IMPACT OF ANALOGICAL VERSUS LOGICAL REPRESENTATIONS OF THEORETICAL CONCEPTS ON RECALL AND PROBLEM-SOLVING PERFORMANCES OF CONCRETE AND ABSTRACT THINKERS

By

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This dissertation is dedicated to my children, Nathan and Claire, to my wife, Linda, to my mother, Maria, and most of all, to the spirit of my father, Nickolas.

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This study investigated gains in recall and problem solving based on interactions between students' primary learning styles or PLS (concrete experience and abstract conceptualization) and instructional packet types or treatment (visual analogies and mathematical formulas). The sample for this study was 75 students who were enrolled in, or who had just completed, introductory anatomy and physiology courses at a middle-sized community college in north-central Florida. Following their informed consent, students completed the Kolb Learning Style Inventory. Students then completed a pretest on arterial blood gas interpretation; their scores indicated no prior knowledge of the material. At least one week from the date of pretest, students were randomly assigned to treatments. Students then completed a posttest, which tested recall and

problem-solving abilities. Two separate ANOVAS were performed, one for the students' mean scores on the recall questions and one for the problem-solving questions. The interactions between PLS and treatment were investigated for both categories of questions.

There were no significant interactions between participants' PLS and treatment, either on recall questions or questions requiring problem-solving abilities. Interactions were noted for both recall and problem-solving questions. For recall questions, a three-way interaction between treatment, PLS, and gender was found at an alpha = .05. Males with abstract PLSs who received mathematical packets scored higher than females with concrete PLSs who received visual analogy packets.

For questions requiring problem-solving ability, there were significant interactions between treatment and gender and between PLS and gender. Males receiving packets using mathematical formulas had higher mean scores on questions requiring problem-solving skills than females receiving the mathematical packets. Males with a PLS of abstract conceptualization had higher mean scores than did females with a PLS of abstract conceptualization.

This study generated evidence that PLS and treatments do not interact to affect performances on recall questions and questions requiring problem-solving strategies. Exploratory analysis showed that treatment and gender interactions, and PLS and gender interactions, may affect performances on questions requiring problem-solving skills.

Further research is needed to determine whether these findings are useful to teachers for the creation and selection of instructional materials.

CHAPTER 1
INTRODUCTION

Visuals fulfill numerous roles in educational texts. One of the functions of visuals is to serve as a "visual analogy." Analogies, whether verbal or visual, are intended to concretize abstract material into a more readily understood form. Duit (1991) defined analogies as the comparison of structures between two domains. The domain that is familiar to the learner is termed the analog and the unfamiliar domain is the target. However, researchers have not investigated the interaction between the learning styles of students and their ability to interpret visual analogies. An individual's learning style refers to his or her preferred method of gathering and processing information. Conceivably, learners may not interpret visual analogies equally well. Learners who prefer learning through concrete experiences may have a difficult time learning abstract concepts without the use of visual analogies, whereas learners who readily conceptualize abstract concepts may not experience enhanced learning through the provision of visual analogies.

Authors may use visuals for decorative purposes, to clarify or reinforce textual-based concepts, or to serve as analogies and mnemonic devices (Levin, Anglin, & Carney, 1987). Visuals, when used

appropriately, have been found to enhance retention of material and problem-solving performance (Peeck, 1974). Paivio (1979) suggested that visuals are stored in two channels within long-term memory, providing for enhanced retention of factual material. On tests requiring problem-solving skills rather than verbatim recall, Mayer (1989) found that students who received labeled illustrations outperformed students who did not receive labeled illustrations. Although they did not control for learner characteristics, Bean, Searles, Singer, and Cowen (1990) found that students receiving pictorial analogies improved their understanding of biological concepts to a greater extent than did students who received textual analogies.

Conceivably, individuals with preferences for concrete experiences would benefit from the concretizing function of visual analogies. Because of this concretizing function, visual analogies may differentially improve abstract concept attainment and problem-solving abilities in learners who prefer learning through concrete experiences, compared to learning gains attained when using mathematical or logical representations of physiologic concepts.

Problem Statement

Newby and Stepich (1987) noted that analogies may provide a concrete substitute for abstract concepts and thus positively affect concept attainment. Visuals also serve as analogies for abstract concepts (Bean et al. 1990; Clement, 1988; Dwyer & Dwyer, 1989; Hurt,

1987; Issing, 1990; Messaris & Nielsen, 1989; Smith, 1989). However, researchers have not explored whether students' learning styles affect their ability to interpret visual analogies. Concretizing abstract principles by providing visual analogies may enhance learning outcomes in individuals who learn best through concrete experiences and examples. Sensitivity to the differential affect of visual analogies on learning, based on an individual's learning style, may have important implications for the design of instructional materials.

Kolb determined that individuals prefer one of four styles or modes for learning new material (Smith & Kolb, 1996). These modes are termed active experimentation, concrete experience, abstract conceptualization, and reflective observation (Davidson, 1990; Davidson, Savenye, & Orr, 1992; Matthews & Hamby, 1995; O'Brien, 1994). Conceivably, the method of presenting information may interact with an individual's learning style and thus may influence learning and concept attainment. Instructional approaches for teaching abstract concepts frequently use mathematical formulas to model the relationships among multiple variables. Learners who prefer concrete experiences may have difficulty attaining or visualizing concepts when these concepts are presented mathematically (Roark, 1998). Because analogies concretize abstract concepts, learners who prefer concrete experiences rather than abstractions should benefit from the use of visual analogies. Failure to recognize this interaction of learning style

and instructional treatment could negatively affect learning outcomes and increase the risk of student failure. Paris and Winograd (1990) noted that "It is *unreasonable to assume that one instructional technique* ... can be used with equal effectiveness for all kinds of tasks, for all kinds of texts, *and for all kinds of students"* [italics added] (p. 42).

This study was designed to determine whether a correlation exists between learning style and instructional treatment (e.g., supplying visual analogies rather than mathematical formulas). If such a correlation exists, educators may facilitate learning by supplying visual analogies to students who prefer concrete learning experiences.

Need for the Study

This study was designed to advance understanding of how primary learning styles interact with instructional media to influence learning outcomes. Clark (1972, 1994) stated that one of the most important perspectives in the design of educational experiences is the consideration of interactions between a mode of instruction and the relevant individual differences of learners. Performance differences on an examination designed to measure learning gains were used as the indicator for interactions between primary learning styles and types of instructional format (mathematical formulas or visual analogies).

Conceivably, educators should provide a variety of instructional approaches that will help learners achieve significant learning outcomes, regardless of the learners' preferred learning styles. This

study was designed to analyze whether multiple presentation formats (mathematical formulas or visual analogies) would improve overall learning outcomes in a sample of learners with preferences for either concrete or abstract learning environments. The effectiveness of the "concretizing" function of visual analogies for abstract concepts was explored.

Finally, the experimental approach adopted for this study was novel in that the identical concept (homeostasis) was presented in two different formats, either as mathematical formulas or visual analogies. Each mathematical formula had an identical visual analogy associated with it. However, participants only had access to one of the instructional formats. Learning gains based on abstract presentations of material (formula) and concrete representations of the concepts (visual analogies) could then be isolated and analyzed.

Definitions

The following terms are used in this dissertation. These terms are used to describe the characteristics of analogies. Terms relating to learning styles are included.

Advance organizer. A familiar, related concept that is presented before introducing a new concept, to facilitate the learning of the new concept (Ausubel, 1960; Mayer, 1978; Mayer, 1979).

Analog. Subject matter that is familiar to a learner that serves as the basis for an analogy (Newby, Ertmer & Stepich, 1995; Thagard, 1992).

Analogy. An explicit, nonliteral comparison between two objects, or sets of objects, that describes their structural, functional, and/or causal similarities (Stepich & Newby, 1988).

Base domain. Subject matter that is familiar to a learner that serves as the basis for an analogy. Equivalent to an analog (Gentner, 1983; Newby et al., 1995).

Learning style. A unique way in which an individual gathers and processes information (Davidson, 1990); a pattern in the way a person accomplishes a particular kind of task that is somewhat resistant to change (Schmeck as cited in Tendy & Geiser, 1997); a biologically and developmentally imposed set of characteristics that affect the effectiveness of instruction for a particular individual (Dunn & Griggs, 1988); and how we perceive new information or experience and how we process what we perceive (Smith & Kolb, 1996).

Mapping. Connecting sets of attributes from a familiar domain to an unfamiliar domain (Armbruster & Anderson, 1984; Gentner, 1983; Gick & Holyoak, 1980; Gick & Holyoak, 1983; Holyoak, 1984; Thagard, 1992).

Primary learning styles. Learners' preferences for either concrete experiences or abstract conceptualization as their primary learning

modes and active experimentation or reflective observation for determining the validity of their experiences (Cornwell & Manfredo, 1994)

Target. An unfamiliar concept that is related to a known concept or domain (analog) in an analogy (Gentner, 1983; Gick & Holyoak, 1980; Gick & Holyoak, 1983; Holyoak, 1984; Newby et al., 1995; Newby & Stepich, 1987; Wong, 1993).

Delimitations

The delimitations of this study include the population/sample, treatments, setting and instrumentation. The population from which the sample was drawn was students enrolled in a north central Florida community college. The participants were enrolled in anatomy and physiology classes or were dental hygiene students who had recently completed their anatomy and physiology coursework. The treatments used in the study were two instructional packets developed by the investigator on the subject of arterial blood gas interpretation. One of the packets used mathematical formulas to teach the topic; the second packet utilized visual analogies to teach the same content. All testing was performed in a classroom located in the health sciences building. The instruments used in the study were the Kolb Learning Style Inventory (Kolb, 1993) and an examination developed by the investigator. The examination consisted of questions that required factual recall and questions that required problem-solving strategies.

Limitations and Assumptions

Interpretation of the results from this study is subject to the following limitations and assumptions.

- The testing of the hypotheses relied on self-reported data and performance on examinations that did not influence participants' grades in courses they were taking. The investigator assumed that participants answered all questions honestly, independently, and to the best of their ability.

- Conclusions from this study are limited to the population represented by the sample. Generalizations to other populations should be made with caution and should be subject to replication of results.

- The published validity and reliability data for the Kolb Learning Style Inventory were assumed to be correct.

- Instructional packets, which used either visual analogies or mathematical formulas, were randomly assigned to the participants in order to reduce threats to internal validity.

Hypotheses

This research focused on whether mathematical expressions and visual analogies interact with learning preferences. Differential learning outcomes based on learning styles were investigated. Two presentation modes were used: mathematical formulas and visual analogies. The investigator analyzed learning, as quantified by a posttest administered after participants read their respective packets. The examination consisted of two types of questions, those requiring simple recall of factual information and those requiring problem-solving abilities. The investigator conducted an analysis of variance on each participant's performance for each category of question.

Hypothesis 1. Mean outcome scores on examinations testing the recall of abstract concepts do not differ due to the interaction of treatment and learning style.

Hypothesis 2. Mean outcome scores on examinations testing problem-solving performance on questions relating to abstract concepts do not differ due to the interaction of treatment and learning style.

The experimental design is shown in Figure 1-1. The experimental model consists of two separate, 2 x 2 designs. The two categories are primary learning style (CE or AC) and instructional packet type (mathematical formulas or visual analogies). The interaction between primary learning styles and packet types was investigated for two types of questions (problem solving and simple recall). Two separate analyses of variance were performed: one for recall questions and one for questions requiring problem-solving skills.

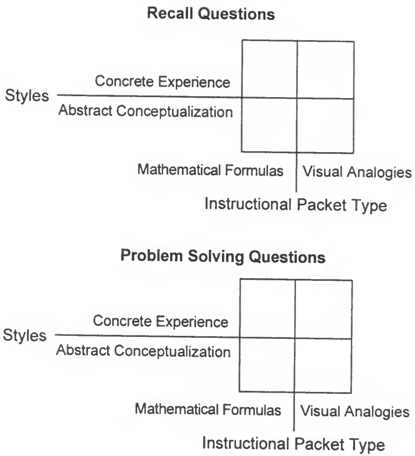

Figure 1-1. Experimental Model

CHAPTER 2
REVIEW OF THE LITERATURE

Introduction

This study focused on the interactions between learning styles and visual analogies and whether visual analogies enhance recall and problem-solving capabilities. This literature review surveys the research on learning styles and how learning styles influence learners' preferences for particular modes of learning. Next, studies investigating the role of analogies in learning and concept attainment are reviewed. The literature pertaining to the roles of visuals in learning is discussed, focusing on how visuals may serve as analogues for abstract concepts.

Review of Learning Styles

The perception that individuals learn differently is not a new one (Fizzell, 1984). The ancient Hindus classified individuals along two bipolar continua: people were either active or passive and either emotional or thoughtful. This classification scheme led to the four basic ways of practicing religion, the four yogas (or paths).

Researchers have defined learning styles in numerous ways. Davidson (1990) defined a learning style as the unique way in which an individual gathers and processes information. Schmeck (as cited in

Tendy & Geiser, 1997) defined style as a pattern in the way a person accomplishes a particular kind of task that is somewhat resistant to change. Focusing on the design of instruction, Dunn and Griggs (1988) defined learning styles as "a biologically and developmentally imposed set of characteristics that make the same teaching method wonderful for some and terrible for others" (p. 3). Maintaining that cognitive style is a permanent attribute of an individual, Messick (1979) stated that cognitive styles are "information-processing consistencies reflective of underlying personality trends. They are stable attitudes, preferences, or habitual strategies determining a person's typical modes of perceiving, remembering, thinking, and problem solving" (pp. 286-287). He believed that cognitive styles are independent of the content of cognition or the level of skill displayed in the cognitive performance. Ultimately, a learning style reflects the means by which an individual prefers to learn. Kolb defined learning style as how a person deals with ideas and day-to-day situations (Smith & Kolb, 1996). Corno and Snow (1986) determined that learning/cognitive styles were "propensities for processing information in certain ways that develop around particular ability-personality intersections" (p. 606). Perry (1994) noted that learning styles arise through a combination of genetics and experiences. "Over time as a result of the complex interaction of inherited factors and experiences in a variety of learning situations, an individual will consistently resolve the dialectic tension between the

polar opposite dimensions in a characteristic fashion and develop a preferred learning style that emphasizes some characteristics over others" (p. 4). Similarly, Cahill and Madigan (1984) defined learning/cognitive style as the way an individual acquires, perceives and processes information in a particular learning situation.

Learning style theorists targeted particular sets of learner attributes when they formulated their theories. Letteri (1980) established a learning style categorization based on whether learners were analytical processors (Type 1), global processors (Type 3) or a combination of global and analytical (Type 2). Letteri believed that analytical processors tolerated ambiguity well and were highly successful in school, compared to global processors who categorized objects and concepts broadly and were intolerant of ambiguity. Type 3 processors frequently were not successful academically. Type 2 learners were moderately successful in school. Letteri posited that learners could have their learning type altered through training and consequently improve their chances for academic success.

Anthony Gregorc (as cited in Tendy & Geiser, 1997) found that some students preferred business-like instructors who presented material in an orderly, step-by-step fashion. Other students preferred instructors who personalized lessons, not focusing exclusively on the text. Gregorc's model has perspective and temporal dimensions. The perspective dimension ranges from concrete to abstract, whereas the

temporal dimension ranges from sequential to random (Benton, 1995, Ferro, 1995, Steward & Felicetti, 1992). Gregorc (1984) believed that successful students could alter their learning style to accommodate learning environments that did not match their preferred mode of learning, whereas students who could not accommodate alternate environments were learning disabled.

Schmeck (as cited in Tendy & Geiser, 1997) similarly believed that learning styles could be altered to fit a particular learning environment. Schmeck defined style as a pattern in the way a person accomplishes a particular kind of task that is somewhat resistant to change. Schmeck proposed that cognitive style is developmentally determined and ranges from global to analytical in nature. Self-actualized individuals use both approaches to learning.

Hill developed his cognitive style model (as cited in Tendy & Geiser, 1997) in order to elucidate cognitive processes and how they help individuals in their search for meaning. He developed the Cognitive Style Interest Survey, which explores how individuals process theoretical and qualitative symbols, modalities of inference, and cultural determinants of cognitive style. Through a detailed analysis of cognitive types, Hill posited that there are 330 different types of cognitive styles (Fizzell, 1984).

Fizzell (1984) developed a learning style assessment based on nine variables. These variables included conceptual approach,

instructional mode, perceptual preferences, curricular interests, time preferences, achievement level, counseling support, social orientation, and social environment. Fizzell's research showed that students who might fail in one program can succeed in another program that serves different styles, even though the second program shares the same goals and standards.

An individual's need for structure in learning activities and whether a learner is peer- or adult-oriented served as the basis for Hunt's learning-style inventory (Hunt, 1987). He proposed that learners could be (a) concrete and impulsive, with a low tolerance for frustration; (b) dependent on rules and authority; or (c) independent and could require more freedom in the way they approached learning tasks.

Dunn and Dunn (1993) developed a more complex model of learning styles. The Dunn, Dunn, and Price Learning Styles Inventory was used to analyze learners' responses to five stimuli: environmental, emotional, sociological, physiological, and psychological. Each of these stimuli has multiple elements (Table 2-1).

Dunn and Griggs (1988) believed that knowledge of an individual's learning styles could provide guidance in terms of the way classrooms should be organized and what type of assignments would motivate a particular learner. Additionally, Rita Dunn recommended that teachers (a) understand the concept of learning styles; (b) explain

the concept of learning styles to students, emphasizing that there are no good or bad learning styles; and (c) have alternate instructional methods available to accommodate different learning styles (Shaughnessy, 1998). Dunn, Griggs, Olson, and Beasley (1995) conducted a meta-analysis of research studies evaluating the effectiveness of learner style accommodation. They found a large body of research showing that students who had their learning styles accommodated achieved approximately 75% of a standard deviation higher on aptitude tests. This finding is particularly significant because Backes (1993) found a correlation between high school dropout rates and the students' learning styles among native American students.

Table 2-1

Dunn, Dunn, and Price Learning Styles Inventory, Stimuli and Elements

Stimulus	Elements
Environmental	Sound, lights, temperature, and design
Emotional	Motivation, persistence, structure, responsibility
Sociological	Self, pairs, peers, team, adult, varied
Physiological	Perceptual, intake, time, mobility
Psychological	Global, analytical, hemisphericity, impulsive, reflective

Basing her system on Kolb's experiential learning model, Bernice McCarthy developed her 4MAT Learning System and devised learning activities that included right and left brain dominance exercises, creativity, and movement (Samples, Hammond, & McCarthy, 1985; Scott, 1994; Smith & Kolb, 1996). Type One learners were described as concrete and perceptual, reflectively processing information. Type Two learners were categorized as analytical, relying on abstract conceptualization and reflective observation as their primary modes for learning. Categorized as using "common sense" in their approach to learning, Type Three learners rely on abstract conceptualization and active experimentation. Finally, Type Four, or dynamic learners, prefer to use concrete experience and active experimentation to assimilate new information. McCarthy used her learning theory to devise activities that would move learners through the concrete experience, reflective observation, abstract conceptualization, active experimentation learning cycle (Samples et al., 1985).

The experiential learning model serves as the theoretical basis for the Kolb Learning Style Inventory (Smith & Kolb, 1996). The core of the experiential learning model is the learning cycle, in which concrete experiences are translated into concepts, which then are used to guide choices for new experiences. With each new experience, the learner tests previously formulated concepts and generalizations; and based on outcomes, either retains or rejects these concepts. The experiential

learning model proposes that learners reflect on their concrete experiences, devise theories or concepts to explain these experiences, and then test these theories or concepts on new experiences.

When he developed the LSI, Kolb (Smith & Kolb, 1996) created a grid that incorporated the four learning modes of experiential learning: concrete experience (CE), reflective observation (RO), abstract conceptualization (AC), and active experimentation (AE) (Figure 2-1). Leonard and Harris (1979) referred to these learning modes as "feeling" (concrete experience), "watching" (reflective observation), "thinking" (abstract conceptualization), and "doing" (active experimentation).

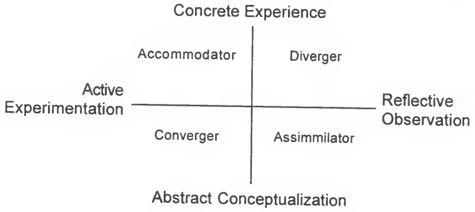

Figure 2-1. The Four Quadrants Comprising the Kolb Learning Style Inventory

Davidson (1990) noted that learning mode scores are used to compute two combination scores, AC—CE and AE—RO. These combination scores are based on polar opposites comprising the active cycle of learning. The AC—CE score reflects a learner's degree of preference for abstract conceptualization compared to concrete

experiences. The AE—RO score shows the degree of preference for active involvement versus passive observation. These combination scores are plotted on a grid to identify an individual's "quadrant" or preferred learning style. CONVERGERS' dominant learning abilities are abstract conceptualization and active experimentation. They perform well in situations using data and objects and where only one correct answer to a problem exists. DIVERGERS' dominant abilities are concrete experience and reflective observation. Their strengths lie in their ability to generate ideas, see concrete situations from many perspectives and work with people. ASSIMILATORS' dominant abilities are abstract conceptualization and reflective observation; they excel in inductive reasoning and assimilating disparate observations into integrated explanations such as theories and models. Lastly, ACCOMMODATORS prefer concrete experience and active experimentation for optimal learning. They are frequently task oriented and rely heavily on other people for information rather than their own analytic ability to gather the information. Each of the four quadrants is sub-divided into inner quadrants that show whether the learner ranks as high, moderate, or low for that particular style.

Researchers have examined learning styles and how they correlate with various student characteristics and academic success. Titus, Bergandi and Shryock (1990) found that adolescents tended to favor concrete learning styles rather than the abstract learning modes

seen in their adult sample. Witkin, Oltman, Raskin, and Karp (as cited in Couch, 1991, p. 134) reported that, when instructional tasks required restructuring in order to encode, store, and retrieve information, field-independent subjects would outperform field-dependent subjects. For example, the field-dependent, field-independent nomenclature proposed by Witkin et al. (1977) was based on a differential ability to view visuals. Field-independent learners were characterized as analytical, self-referent, and impersonal; whereas field-dependent learners were characterized as globally oriented, socially-sensitive, and concerned with interpersonal interactions (Messick, 1979).

Recent analyses of the Kolb LSI raised a number of concerns regarding its validity and reliability. These concerns are reviewed in Chapter 3 (p. 46).

Individuals' learning styles affect how they prefer to learn. Analogies also have been shown to have positive effects on learning. The following is a review of the literature regarding the nature and instructional benefits of analogies.

How Analogies Promote Learning

Aristotle defined "classical analogies" as comparisons among terms in the analogy, usually represented in the format of A:B::C:D (Goswami, 1992). The relationship between the C and D terms should be equivalent to the relationship linking the A and B terms. The ability

to conceptualize this quality of relations is recognized as the "hallmark" of analogical reasoning. Similarly, Goswami (1992) discussed the phenomenon of "problem analogies" in which the characteristics of a solution for a base problem is applied to solving an analogous target problem. Goswami (1992) reported that children frequently were unable to see the intended relational correspondence between the base and target problems, even though the relationship was evident to the experimenters.

Research highlights the role of analogies in concept attainment. When learners are confronted with unfamiliar material, provision of advance organizers and analogies are thought to enhance learning. Ausubel (1960) stated that advance organizers (AO) are useful for learning unfamiliar but meaningful verbal material by providing relevant subsuming concepts. Analogies promote learning by "concretizing" abstract concepts for the learner, promoting the assimilation of ambiguous or intangible concepts (Newby & Stepich, 1987). Frequently, students are required to conceptualize processes not readily perceivable and it is believed that analogies may help fulfill this role (Lawson, 1993). Gick and Holyoak (1980) found that analogies enhanced a subject's ability to critically analyze and suggest a solution to a problem, as long as the subject recognized the similarities between the problem and the analogy. Furthermore, if mapping support from an analog to a target is not provided by the instructor, the potential for

misunderstanding is created (Duit, 1991). Mayer and Gallini (1990) found that illustrations consistently improved performance on the recall of conceptual rather than non-conceptual information and that illustrations promoted creative problem solving rather than enhanced verbatim retention.

Mayer (1979) found that advance organizers (AO) must meet four criteria if they are to promote learning:

1. The AO facilitates comprehension of some or all of the relationships found in the new material.
2. The AO helps the learner relate the unfamiliar material with material that was previously learned.
3. The AO is easily learned.
4. The AO is likely to be used by the learner.

The similarities between the attributes required by effective advanced organizers and attributes of effective analogies are apparent.

Role of Analogies in Concept Attainment

Mayer (1989) cited four criteria that must be met if conceptual models are to be effective in promoting learning. Conceptual models are words and/or diagrams that are intended to help learners build mental models of the system being studied. Two of these criteria relate directly to the design of the study: the material to be learned must be explanative rather than descriptive or narrative in form and the major dependent measures should focus on problem-solving performance rather than verbatim recall. If post-testing consists of questions

requiring verbatim recall, conceptual models will not enhance learning outcomes. Mayer also noted that the learners must be novices rather than experts if the conceptual models are to result in improved posttest scores.

With regard to conceptual models, visual analogies should effectively function in this role by "concretizing" abstract concepts for the learner, promoting the assimilation of ambiguous or intangible concepts (Newby & Stepich, 1987). Gabel and Sherwood (1980) found that students who were at the concrete-operational developmental level improved performance in their chemistry through the use of analogies. In contrast, students who were at the formal operational level of development benefited most from the completion of additional practice problems rather than from the analogies.

Attributes of Effective Analogies

In order for an analogy to be effective, regardless of whether the analogy is text-based or visual, Gentner (1983) recommended that analogies should meet the following criteria:

- The base domain should be familiar and understood by the learner (base specificity).
- Object mappings should be precisely defined (clarity).
- There should be a large number of predicates (or characteristics) that are mapped from the base to the target (richness).
- The greater the number of higher order relationships between the base and target, the more abstract and effective the analogy or mapping (abstractness).

- The predicates in the two domains must be correct (validity).
- There should be a large number of possible cases to which the analogy can be applied validly (scope of applicability).

These recommendations were incorporated into the visual analogies developed for this investigation.

Newby et al. (1995), Newby and Stepich (1987), Stepich and Newby (1988a) and Stepich and Newby (1988b) reported similar recommendations for analogy design. Additional considerations regarding the student's learning level (Newby et al., 1995, Stepich & Newby, 1988a) and the point in the learning process at which analogies were presented (Newby & Stepich, 1987; Schustack & Anderson, 1979; and Stepich & Newby, 1988a) were found to be significant.

Glynn (1991) developed the Teaching With Analogies (TWA) model for using an analogy to explain science concepts, based on his research of 43 science texts. For maximum effectiveness, the instructor should ensure that six operations occur:

1. The target must be introduced.
2. Cue retrieval of the analog must occur.
3. Relevant features of the target and analog are identified.
4. Similarities between the target and analog are mapped.
5. Conclusions about the target are drawn.
6. Areas in which the analogy breaks down are described.

Glynn's TWA model contains similar recommendations as those made in an instructional model for analogies developed by Radford (1989), who stressed the role of an analogy as an advanced organizer.

Brown (1994) and Clement (1993) found that the use of multiple bridging analogies between an anchor and target would facilitate learning. For example, Brown investigated the physical concept of force. The anchor illustration was a hand pressing down on a spring; the target was whether a book resting on a table would "experience" an upward force from the table. The bridging illustrations were a book on a spring, a book on a flexible board between two saw horses, and a book on a table. Brown found that concept attainment was enhanced through the use of these bridging analogies, minimizing some of the dangers inherent in the use of analogies.

Advantages and Problems Associated with Analogies

Five advantages of using analogies in teaching were noted by Duit (1991), especially in relation to the constructivist view of learning (p. 666):

1. They are valuable tools in conceptual change learning, which open new perspectives.
2. They may facilitate understanding of the abstract by pointing to similarities in the real world.
3. They may provide visualization of the abstract.
4. They may provoke students' interest and may therefore motivate them.

5. They force the teacher to take the students' prior knowledge into consideration. Analogy use may also reveal misconceptions in areas already taught.

Duit (1991) also noted problems with the use of analogies. Only the deep structure aspects of an analogy provide inferential power, surface similarities providing little benefits in terms of learning. In addition, because an exact fit between the analog and target never exists, features of the analog may mislead students. Finally, students must draw the intended analogies themselves. Dagher (1995) stated the following:

> While instructional analogies provide a bridge between what is known and what is less known, some fear that this bridge has an elusive quality that could lead those traversing it into side tracks that interfere with their arrival to the intended destination. (p. 296)

Thiele and Treagust (1994) found that teachers tended to select analogs from their own experience, rather than using analogs that may be more familiar to the students. As a result, students frequently had difficulty in understanding the analog's relevance, especially when the teachers did not explicitly map the relevant attributes and limitations of the analog and target. Dagher (1995) stressed that teachers should have an understanding of learners' prior knowledge so that they may select analogs that are readily assimilated into existent knowledge structures. In a study by Gabel and Sherwood (1980), the researchers found that 48% of the students participating in the study did not

understand 90% of the analogies used by teachers in an experimental treatment.

Although analogies are frequently text-based, visuals may also serve an analogical role. A large body of research has examined the role of visuals in education and in concept attainment.

Visuals and Their Affect on Learning

Levin et al. (1987) identified five categories of visuals used in educational texts and discussed each of these categories' role in terms of knowledge acquisition. Table 2-2 summarizes these categories and their roles. Specifically, Levin et al. (1987) stated that transformational visuals affect a student's memory through four mechanisms.

1. Targeting the critical information to be learned.
2. Recoding the information into a more concrete and memorable form.
3. Relating the separate pieces of information into a well-organized context.
4. Providing for the retrieval of information when required (p. 61).

Interpretational pictures fulfill the requirements of an advance organizer in that they provide "stage-setting support" for complex concepts (Levin, et al, 1987, p. 58). In the absence of concrete or direct experiences, inclusion of analogies should help prepare the learner for more abstract, complex experiences (Curtis & Reigeluth, 1984, p. 108). Similarly, Stencel (1997) referred to simple paper models that served as analogies for cells and organic materials as "visual imprints" that

facilitated learning (p. 235). Gambrell and Bales (1986) found that poor readers benefited from visual analogies because the visual constructs served as anchors for newer concepts.

Table 2-2

Categories of Visuals and Their Role in Knowledge Acquisition

Type of Visual	Role in Knowledge Acquisition
Decorative	No role in knowledge acquisition
Representational	Used to reinforce the major features or topics contained within the narrative
Organizational	Clarifies procedures that were outlined in the text
Interpretational	Serves to clarify difficult concepts or passages contained in the narrative
Transformational	Functions as a mnemonic device through a number of mechanisms

Similarly, Ault (1985) stated that, in order for learners to grasp concepts, those concepts must first be integrated into existing memory. Because concrete concepts are easier to integrate, instructors should initially present concrete images and concepts. Once these are integrated into the learner's memory, the learner will be able to "map" or attach new concepts to them. Analogies will help to concretize abstract concepts (Newby & Stepich, 1987; Simons, 1984).

Other researchers categorized visuals into three categories: realistic, logical, and analogical (Issing, 1990; Knowlton, 1966; Levie, 1987). A realistic image portrays the surface features of an object with a high degree of fidelity. Illustrations frequently fall within this category. Knowlton (1966) defined a logical picture as "a visual representation wherein the elements are arbitrarily portrayed, while pattern and/or order are isomorphic with the state of affairs represented" (p. 178).

Logical (or arbitrary) images, include diagrams, graphs, maps, circuit diagrams and flowcharts (Issing, 1990; Knowlton, 1966). If the intent of the visual is to function as an analogy for a DNA molecule, the visual would be analogical in nature. In effect, the "portrayed objects "participate" in a manner common to the less familiar process ... in the state of affairs that is of interest" (p. 177). Knowlton found that this use of visuals is most dramatic when representing the non-phenomenal world. A subset of analogical pictures includes illustrations that are drawn to concretize a theory (such as a drawing of the structure of an atom). Issing (1990) noted that the inclusion of humorous or stimulating elements as components of the analogy would increase their effectiveness.

The role of a particular visual may change, depending on the intent of the author. For example, a picture of a cloth cutter using a

template would serve as a realistic picture if the text were referring to a cloth cutter, clothing factory, or clothing templates (Knowlton, 1966).

The interpretational and transformational pictures of Levin et al. (1987) and the analogical and logical visuals described by Knowlton (1966) provide the learner with many of the benefits associated with the inclusion of analogies. They help to concretize abstract concepts and to relate new and unfamiliar material with material that is already familiar to the learner. However, a learner must correctly interpret a visual if the visual is to enhance learning.

Interpretation of Visuals

Defining visual literacy and analyzing how learners relate to visuals are complex problems. A great deal of confusion exists because establishing a definition of visual literacy is problematic (Seels, 1994). Seels and Lenze and Dwyer (1993) divided the concept of visual literacy into three sub-concepts: visual thinking, visual learning, and visual communication. Debes (as cited in Levie, 1978) proposed one of the most widely promulgated definitions of visual literacy, specifically that a visually literate person can interpret "the visual actions, objects and/or symbols, natural or man-made" encountered in the environment. Levie (1978) pointed out that Debes' definition includes the ability to read words and that reading ability, ultimately, accounts for some of the difficulties associated with the research on visual literacy:

> It is, of course, this latter ability—verbal literacy—with which visual literacy is often contrasted. The key problem with Debes' definition is that . . . it defines the stimuli of interest in terms of a sensory modality rather than a symbolic modality. (p. 26)

Levie (1978) believed that the interpretation of pictures requires fundamentally different mental processes than the interpretation of words and other digital symbols. Expanding on the work of Paivio (1979), Levie noted that images are concrete and processed simultaneously, in contrast to words that are abstract in nature and processed sequentially. Although both systems are interconnected, they can work independently. Mental imagery and visual thinking are the independent operations of the imaginal system. These independent processes are the internal link within the "iconic mode." In the iconic mode, images are stored or internalized as mental representations and externalized in the form of pictures. Figure 2-2 shows the iconic mode proposed by Levie. Similarly, Lenze and Dwyer (1993) viewed visual thinking as the mental imagery of visual concepts and relate these to the internal thought processes of the learner.

Many factors influence how readers interpret visuals, including culture and experience (Goldsmith, 1987), cultural and ethnic background (Hurt, 1989), general education (Messaris & Nielsen, 1989), gender, learner, and ethnic influences (Randhawa, Back, & Myers, 1977), learner experience (Tierney & Cunningham, 1984), Piagetian level (Gabel & Sherwood, 1980) and cognitive style (Witkin et al., 1977).

Figure 2-2. Levie's Iconic Mode. Note. From "A prospectus for instructional research on visual literacy," by W. Levie, 1978, Educational Communication & Technology Journal, 26, p. 27. Copyright 1978 by the Association for Educational Communication and Technology, Inc. Adapted with permission.

Seels (1994) defined visual thinking as the internal reaction stage of visual literacy, involving "more manipulation of mental imagery and more sensory and emotional association than other stages" (p. 104). She defined visual learning as the acquisition and construction of knowledge as a result of interaction with visual phenomenon and visual communication as "using visual symbols to express ideas and convey meaning" (p. 109).

Research in learning theory has shown that learners view images differently, based on their learning styles, educational levels, age, and cultural backgrounds. Witkin et al. (1977) found differing abilities to locate embedded figures, based on whether subjects were field-independent or field-dependent. Macnab, Hansell and Johnstone (1991) examined field-independence/ dependence in students ranging from 8 to 19 years of age and tested their ability to recognize microscopic specimens in various orientations. The investigators found that few

field-dependent students were in upper level biology courses and speculated that students who were field dependent were progressively filtered out during their school years and in the early stages of tertiary education. Messaris and Nielsen (1989) found a relationship between educational level and a subject's ability to interpret an associational montage, a juxtaposition of visual images that is intended as an analogy.

In addition, investigators showed that age, cultural background, and previous academic abilities influence learners' ability to interpret visuals. Constable, Campbell and Brown (1988) found that very few 11 year-old British students could identify the cut surfaces of objects in biological illustrations. Hurt (1989) posited that cultural background influenced the ability of children to interpret visual conventions, whereas Koran and Koran (1980) determined that inductive reasoning scores were inversely related to performance gains associated with use of diagrams. Low-ability subjects benefited most when a diagram was included as an adjunct to the text, regardless of the diagram's position in the text, whereas high-ability subjects performed best without the drawing. Similarly, Lin, Shiau, and Lawrenz (1996) determined that students taught with pictorial analogies scored significantly higher than their counterparts, but that low achievers benefited more from this approach than high achievers.

Problem Solving and Analogical Visualization

The history of scientific inquiry is replete with examples illustrating the importance of analogies and visualization in problem solving and cognition. Perhaps one of the earliest examples of analogical reasoning and the solution of problem was reported by Archimedes (Goswami, 1992). Archimedes was unable to determine whether base metal had been substituted for gold in the construction of an elaborate crown made for the king, although the weight for volume of pure gold was known. The problem was how to determine the volume of the intricately designed crown. It was not until Archimedes stepped into his bath that he had his “Eureka” moment and was able to solve the problem. Rieber (1995) described the process of illumination, where solutions to problems came to scientists and researchers in “sudden bursts of insight” (p. 48). For example, Kekulé reported that he frequently imagined atoms dancing before his eyes. One day, while gazing into a fire, chains of atoms transformed themselves into snakes that grabbed their own tails and started spinning before his eyes. Through this utilization of visualization, Kekulé was able to elucidate the structure of benzene. Einstein reported that many of his fundamental insights were the result of experiments performed in his imagination, using creative imagery as his laboratory (Finke, 1990).

Analogies, whether textual or visual, were found to improve performance on examinations requiring problem solving or critical thinking. Weinstein and Mayer (1986) included imaging as a cognitive strategy that influences the learner's encoding process. Using Duncker's radiation problem, Gick and Holyoak (1980, 1983) found that investigator-supplied analogies increased the likelihood that learners would arrive at a creative solution to the problem. Briefly, Duncker's radiation problem describes a hypothetical patient with a large abdominal tumor. Subjects were told that a beam of radiation with enough energy to kill the tumor would also destroy the surrounding tissue as it passed through it, resulting in the death of the patient. If Gick and Holyoak first presented subjects with a story of an army that split into smaller units to attack a castle from multiple routes, the subjects suggested that the physician use multiple converging, lower-energy radiation beams to destroy the tumor. However, without a hint from the investigators to use the story, most learners did not spontaneously use the analogy to solve the problem.

When learners are presented verbal and visual material, Mayer and Anderson (1991) found that, in order for problem solving to occur, the learners must construct representational and referential connections. Representational connections are connections that are made between verbal stimuli and verbal representations within long term memory. Similar representational connections also are made

between visual stimuli and their visual representations. Mayer and Anderson stated that problem solving requires that the learner create referential connections between the verbal and visual representations within long-term memory. In their study, college students were better problem solvers when related verbal and visual stimuli were presented simultaneously, rather than serially, due to the facilitation of referential connections between visual and verbal stimuli. The instruments developed for this study will present the visual and verbal information simultaneously.

Lin, Shiau, and Lawrenz (1996) concluded that most of the studies investigating the effects of analogies on learning focused primarily on students' "algorithmic problem-solving ability" rather than their "conceptual problem-solving ability." Students were able to correctly apply formulas to solve problems in chemistry, even though they did not learn the underlying concepts relevant to the problems. They concluded that conceptual problem solving was enhanced through the use of pictorial analogies, especially in low achievers. Research by Nakhleh (1993) confirmed that students' conceptual problem-solving abilities lagged far behind their algorithmic problem-solving abilities. She found that college chemistry students were able to use formulas and algorithms to solve problems, without being able to interpret drawings that illustrated the problems' underlying physical concepts. In his review of visualization and scientific inquiry, Rieber (1995)

concluded that problem solving through the use of imagery was inappropriately discounted as unsophisticated and not as powerful as more complex and abstract approaches.

Summary and Conclusions

Learning styles reflect the unique ways that individuals gather and process information (Davidson, 1990). Learning-style theorists categorized learners in many different ways, including preferences for a particular learning strategy (Cahill & Madigan, 1984; Corno & Snow, 1986; Messick, 1979; Perry, 1994; Smith & Kolb, 1996) and learner attributes (Dunn & Dunn, 1993; Fizzell, 1984; Gregorc, 1984; Letteri, 1980). Theorists differ on whether learning styles are permanent attributes of an individual (Messick, 1979) or vary based on learning task (Baker, Wallace, Bryans, & Klapthor, 1985; Gregorc, 1984). Interactions between learning styles and instructional tasks were found to affect academic success (Witkin, Oltman, Raskin, & Karp, as cited in Couch, 1991). Dunn and Griggs (1988) posited that one mode of teaching may be effective for some learners and "terrible" for learners with different learning styles (p. 3).

David Kolb (Smith & Kolb, 1996) based the Kolb Learning Style Inventory (LSI) on experiential learning theory. The Kolb LSI determines an individual's relative emphasis on four learning modes or orientations (concrete experience, active experimentation, reflective observation, and abstract conceptualization) and on two combination

scores (Abstract Conceptualization—Concrete Experience) and (Active Experimentation—Reflective Observation). Conceivably, students' preferences for concrete learning experiences may adversely affect their ability to learn concepts that are presented in an abstract fashion. Analogies may serve as concrete substitutes for abstract concepts and thereby positively affect concept attainment (Newby & Stepich, 1987). Visuals also may function as analogies for non-phenomenal or the abstract concepts (Issing, 1990; Knowlton, 1966; Levie, 1987).

The purpose of this research was to determine if students' primary learning styles (abstract conceptualization or concrete experience) interact with instructional packet types (mathematical formulas or visual analogies), thereby enhancing students' recall of factual information and/or improving their problem-solving skills. The remainder of this paper will present the methodology for the research, analysis of the results, and recommendations for future research.

CHAPTER 3
METHODOLOGY

This study was designed to determine if learning style influenced a participant's ability to use visual analogies to comprehend new information and whether the visual analogies enhanced the participant's problem-solving skills. This chapter contains a description of the research design and methods used to support the validity and reliability of the measures used in the experiment.

Research Design

The interaction between primary learning styles and representational packet type was investigated for two types of questions (problem solving or simple recall). Two separate analyses of variance were performed, one for recall questions and one for questions requiring problem solving.

Each factor studied had two learning outcome measures. Factor A (subject learning style) was either concrete or abstract. Factor B (type of instructional packet) used a visual analogical approach to instruction or a mathematical approach. Learning outcomes were the subject's performance on recall questions and questions that require problem-solving skills. Each subject was categorized under a level of

factor A (learning style) and randomly given one of the instructional packets (factor B). Performance gains on specific types of questions were determined when the examinations were scored. The investigator-generated examination was used as the posttest.

Population and Sample

The sample for this study was 75 students enrolled in introductory anatomy and physiology courses and dental hygiene students who had completed college-level anatomy and physiology coursework at a middle-sized community college located in north central Florida. The number of males and females in the sample, their primary learning styles, and the number of who were in the visual group and in the mathematical group are presented in Table 3-1.

Table 3-1

Description of Participants in Sample

	Males	Females	Total
Number	18	57	75
Concrete Learning Style	4	28	32
Abstract learning Style	14	29	43
Visual Analogy Packet	10	34	44
Mathematical Packet	8	23	31

The population from which the sample was selected, was chosen for three reasons:

1. The students have a basic understanding of the structure and function of the human body.
2. The students were unlikely to have a background in the interpretation of arterial blood gases, the content used in the treatment. Students who were enrolled in respiratory care, paramedic, or nursing programs might have been exposed to that content during classroom, laboratory, or clinical coursework.
3. The curriculum for anatomy and physiology does not require students to interpret arterial blood gases as part of their coursework.

Written, informed consent from the participants was required due to the nature of the study (see Appendix A).

Materials and Measures

The Kolb Learning Style Inventory was used to determine the students' primary learning styles (PLS). Primary learning styles are defined as the individuals' preferences for either concrete experiences or abstract conceptualization as their primary learning modes and active experimentation or reflective observation for determining the validity of their experiences. The PLS (along the abstract conceptualization/concrete experience continuum) for each participant was determined, but not their learning style type. In addition, the scrambled version of the LSI was administered to eliminate the possibility of response set threats to validity. The instructional packets were developed by the investigator and covered the major concepts important in the interpretation of arterial blood gas results. The works of Gentner (1983), Newby et al., (1995), Ortony (1975), Smith (1989),

and Stepich and Newby (1988b), and Mayer and Anderson (1991) served as guides for the construction of the analogies that were used in the study. The investigator was unable to use any existing materials for two reasons.

1. The literature currently does not use visual analogies to teach the concept of arterial blood gas (ABG) analysis. As a result, this approach had to be developed by the investigator.

2. The major focus of both packets was to provide a conceptual framework for ABG interpretation rather than an exhaustive treatise.

Packet Design

The instructional packets used in the study covered the following topics:

- The determinants of the partial pressure of carbon dioxide gas in arterial blood ($PaCO_2$) that include carbon dioxide production and ventilation.

- The determinants of the pH of arterial blood that include $PaCO_2$ and bicarbonate levels (HCO_3).

- Normal laboratory values associated with arterial blood, including pH, $PaCO_2$, HCO_3, hemoglobin, and oxygen (PaO_2).

- A method for predicting a patient's PaO_2.

Information regarding the determinants of $PaCO_2$ and pH was presented in the form of visual analogies or as mathematical formulas (see appendices B and C). Normal blood values and the method for predicting a patient's PaO_2 were presented as identical textual passages in both the visual analogy and mathematical formula packets.

The visual analogy for the determinants of $PaCO_2$ consisted of a picture of a tub, a faucet, and a drain. A picture of a pointing hand indicated the original level of fluid in the tub. Drops of water from the faucet indicated the relative flow of water into the tub; drops of water exiting the drain represented the relative flow of water out of the tub. As long as the flow of water from the tub equaled the flow of water into the tub, the water level would remain constant. Once the visual analogy was presented, the narrative explained how the water flowing into the tube was analogous to carbon dioxide production, the water flowing out of the tub was analogous to ventilation, and the level of water within the tub was analogous to $PaCO_2$. Carbon dioxide production and alveolar ventilation were the independent variables and $PaCO_2$ was the dependent variable.

The visual analogies for the determinants of arterial blood pH were a series of scales with a balance indicator pointing at a "comfort scale" that indicated a comfort zone or, to its left, acid indigestion. The first visual analogy was a picture of the scale with nothing on either of the balance plates. The second visual analogy showed a jalepeno pepper on the left balance plate and an antacid tablet on the right balance plate. The scale was balanced and the balance indicator pointed into the "comfort zone." The next visual analogy revealed an additional pepper added to the left balance plate; the scale tipped to the left and now indicated acid indigestion. Once a second antacid

tablet was added to the right side of the scale, the scale was balanced and the balance indicator again pointed into the "comfort zone." After the presentation of these four visual analogies, $PaCO_2$ was substituted for the jalepeno pepper and HCO_3 was substituted for the antacid buffer tablet. The comfort scale changed to a pH scale, with a normal pH in the middle of the scale, and acidotic pH on the left side of the scale, and an alkalotic pH on the right side of the scale. $PaCO_2$ and HCO_3 were the independent variables and pH was the dependent variable.

In both of these visual analogies, the concept of homeostasis was presented. By using images of common objects, a relatively abstract concept was presented in a concrete fashion. The visual analogies permitted subjects to mentally manipulate intangible substances (carbon dioxide production and ventilation; $PaCO_2$ and HCO_3) and to predict the effects of this manipulation on dependent variables ($PaCO_2$ and pH respectively).

The following discussion describes how the analogies developed for this investigation possess the attributes of effective analogies.

- *The base domain should be familiar and understood by the learner (base specificity).* The base domain for the determinants of $PaCO_2$ of either a tub with water flowing into it or out of it at varying rates is conceptually simple. The base domain for the determinants of pH is a balance, a conceptually familiar device.

- *Object mappings should be precisely defined (clarity).* In both analogies (tub and balance), the description of the relationships are clearly stated and multiple examples are provided.

- *There should be a large number of predicates (or characteristics) that are mapped from the base to the target (richness).* All of the determinants of $PaCO_2$ and of pH are conveyed through the analogies. For example, the determinants of $PaCO_2$ are alveolar ventilation and carbon dioxide production. Alveolar ventilation and carbon dioxide production are represented in the base domain by the rate of drainage from the tub and by the rate of water entering the tub from the faucet.

- *The greater the numbers of higher order relationships between the base and target, the more abstract and effective the analogy or mapping (abstractness).* The target domain consists of extremely abstract processes (carbon dioxide production and alveolar ventilation), processes that are not readily observable. The example of the tub, faucet, and drain "concretize" these two abstract processes. The balance analogy has a higher level correlation with increases in $PaCO_2$ in that the peppers are related to acid indigestion, a condition associated with a drop in the pH of the stomach. Similarly, as a patient's $PaCO_2$ increases, his pH will fall.

- *The predicates in the two domains must be correct (validity).* The characteristics of the base and target domains are correctly stated and accurately represented by the visual analogies. Levels of carbon dioxide in arterial blood are determined by carbon dioxide production and alveolar ventilation. In addition, levels of carbon dioxide and bicarbonate (HCO_3) determine the pH of the arterial blood.

- *There should be a large number of possible cases to which the analogy can be applied validly (scope of applicability).* Virtually all examples of homeostasis may be represented by the analogy of the tub, faucet, and drain. Similarly, pH levels fall whenever $PaCO_2$ increases, while pH will rise when HCO_3 levels rise. For example, this visual analogy would provide a conceptual basis for the determinants of a lake's water level (flow of water in and out of the lake basin), bank balances (equal deposits and withdrawals), and a person's weight (caloric intake versus caloric expenditure).

Five registered respiratory therapists, who taught in respiratory care programs, independently reviewed the two packets for equivalency of content. The investigator developed the examination used in the study (Appendix D). The examination contained 11 questions that were recall-based and 14 questions that required problem-solving

(interpretive) skills. There were no references to the analogies in the test or any questions that could not be answered from the non-analogical (mathematics) learning packet. All five therapists were able to differentiate the recall questions from those requiring problem-solving skills. The recall questions on the posttest examination had a reliability of 0.50 and a split-half analysis of the problem-solving questions yielded a reliability of 0.48.

The concept underlying the visual analogies used in the analogy packet was that of homeostasis. This concept was represented by two different visuals: (a) a faucet, tub, and drain and (b) a balance. The learner's first exposure to each of these visuals was the baseline condition, in which all components are in balance and normal. Alterations in the baseline condition for each of these visuals will be illustrated with additional images.

Recently, a number of concerns were raised regarding the validity and reliability of the Kolb LSI. The following discussion reviews these concerns.

Kolb Learning Style Inventory: Validity and Reliability Issues

David Kolb revised his Original Learning Style Inventory (OLSI) in 1985 in response to criticisms regarding the OLSI's format, language, reliability, normative samples, instructions and scoring (Smith & Kolb, 1996). The 1985 Learning Style Inventory (LSI 1985) was designed to measure individuals' learning styles, styles that are derived from

Experiential Learning Theory. The test is a 12-item questionnaire that requires respondents to rank-order four sentence endings that correspond to the four learning modes (i.e., Concrete Experience, Abstract Conceptualization, Active Experimentation and Reflective Observation). Scoring the test reveals an individual's relative emphasis on these four learning modes or orientations, and on two combination scores (Abstract Conceptualization—Concrete Experience) and (Active Experimentation—Reflective Observation).

The Kolb LSI has been widely studied in terms of its reliability. Gregg (1989) used Cronbach's Standardized Scale Alpha and found that the LSI displayed good internal reliability for the four basic scales and the two combination scores. Smith and Kolb (1996) reported that the 1985 LSI had very good internal reliability, based on Cronbach's Standardized Scale Alpha, especially for the abstract conceptualization-concrete experience scale (.88). Tukey's Additivity Power test indicated that the combination scores (abstract conceptualization-concrete experience and active experimentation and reflective observation) showed nearly perfect additivity (1.0 and 0.99 respectively). In addition, Pearson correlations among the LSI 1985 scales showed the strongest negative correlation between polar opposites on the experiential learning cycle (abstract conceptualization and concrete experience and active experimentation and reflective observation). No relationship

exists between the two combination scores, indicating statistical independence.

Ruble and Stout (1990) found that factor analyses failed to support the construct validity of the LSI 1985 and suggested that there was a response set present. They attributed this possibility to the columnar format for the revised instrument, in which words referring to a particular attribute, (either feeling, doing, watching, or thinking) occurred within the same column. Sims, Veres, Watson, and Buckner (1986) voiced a similar concern. In response to these criticisms, Kolb (Smith & Kolb, 1996) revised the LSI so that terms describing learner attributes are scrambled, eliminating the threat to validity created by response sets. The newest version of the LSI, LSI-IIA has a high test-retest reliability (Hay/McBer, 2000). Veres, Sims, and Shake (1987) found that the LSI 1985 had improved coefficient alpha estimates for internal consistency over the original form for the four LSI scales. Using two groups of subjects (college-aged students and individuals working in industry). Veres et al. (1987) reported the following alpha estimates (student/industrial): concrete experience: .76/.82; reflective observation: .84/.85; abstract conceptualization: .85/.83; and active experimentation: .82/.84. Similar findings were later reported by Smith and Baker (1996).

Baker et al. (1985) stressed that learning styles are highly situational. Focusing on anesthesia residents, Baker et al. (1985)

found that residents who had just spent 10 hours in the operating room scored higher in terms of concrete experience learning preferences when compared to residents who had just attended a lecture. This finding could explain the lack of reproducibility of learning styles when the LSI is administered over time (Sims et al. 1986). However, Sims et al. did find that the internal consistency of the LSI 1985 was improved over the OLSI.

Using factor analysis, Cornwell, Manfredo, and Dunlop (1991) and Geiger, Boyle, and Pinto (1992) found that the learning styles that loaded as polar opposites were Active Experimentation and Abstract Conceptualization, rather than Active Experimentation and Reflective Observation or Abstract Conceptualization and Concrete Experience as proposed by Kolb. In addition, Geiger et al. (1992) determined that Concrete Experience and Reflective Observation loaded on the same factor. These findings resulted in the authors questioning the theoretical construct of Experiential Learning on which Kolb based the LSI (Smith & Kolb, 1996).

The Kolb LSI uses ipsative measures, in which each score for an individual is dependent on his or her own scores on other variables (Ruble & Stout, 1994). However, scores obtained from ipsative measures are independent of and not comparable with the scores of other individuals (Hicks, 1970). Consequently, ipsative measures only are useful for studying intra-individual preferences (Hicks, 1970 and

Pedhazur & Schmelkin, 1991). Pedhazur and Schmelkin noted that ipsative measures cannot be meaningfully interpreted relative to a group mean.

Ruble and Stout (1994) raised an additional concern regarding the LSI's utilization of ordinal rankings and the loss of information inherent to ordinal scales. For example, two subjects could have the dramatically different learning mode scores (CE, RO, AC and AE) yet have the same learning style (Table 3-2). Based on these results, these two subjects would have the same learning style profile. However, Subject 1 strongly prefers concrete experiences to other learning approaches, whereas Subject 2 only has a mild preference for concrete experiences. This limitation weakens the relationship between the empirical indicators (numerical rankings) and the theoretical constructs (the respondent's preferred learning ability). As a result, the measurement's validity is reduced (Ruble & Stout, 1994).

Table 3-2

Hypothetical Results for Two Subjects with the Same Learning Style (Diverger) but Different Learning Mode Scores

	Subject 1	Subject 2
CE	80	32
RO	12	30
AC	6	20
AE	2	18

Cornwell & Manfredo (1994) validated the discriminant/convergent validity of an individual's primary learning style (his or her score on the abstract conceptualization/concrete experience continuum). For this reason, this study focused on subjects' primary learning styles and not the learning-style types defined by Kolb (accommodator, diverger, converger, assimilator). In addition, the scrambled version of the LSI was administered, to remove the possibility of response set threats to validity.

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The Kolb LSI was used for determining the learning style of the study participants for the following reasons:

- The learning style score of each individual was not compared to other participants. It was used to determine the learning preference for the particular individual (Hicks, 1970; Pedhazur & Schmelkin, 1991).

- The scrambled version of the LSI was used for the study, to eliminate the possibility of a response set, a concern expressed by numerous investigators (Ruble & Stout, 1990; Sims et al. 1986).

- Learning style types were not determined to the level of converger, diverger, assimilator, or accommodator. Instead, I determined the primary learning style of the participants, because these were shown to possess discriminant/convergent validity (Cornwell & Manfredo, 1994).

- The LSI's two bipolar dimensions, abstract conceptualization/ concrete experience and active experimentation/reflective observation, represent the degree to which a learner prefers to learn, either through active involvement or through abstract conceptualization. The purpose of this study was to determine whether a learner who prefered concrete experiences would benefit from a visual analogy, an instructional approach that concretizes abstractions. Other learning style inventories analyze learning style issues other than abstract conceptualization and concrete experiences. For example, the Dunn, Dunn, and Price LSI considers environmental, emotional, sociological, physiological, and psychological factors (Dunn & Dunn, 1993). Hill's Cognitive Style Interest Survey (as cited in Tendy & Geiser, 1997) explores how individuals process theoretical and qualitative symbols, modalities of inference, and cultural determinants of cognitive style.

- Experiential Learning Theory (ELT), which serves as the basis for the LSI, parallels the fundamental processes involved in the utilization of analogies. Issing (1990) noted that learners compare the base domain of an analogy to its target domain. During reflective observation and abstract conceptualization, individuals formulate new theories that are tested through active experimentation and concrete experiences. If the theories predict the experimental outcomes, the theories are retained. If the experimental outcomes do not validate the theories, they are rejected (Smith & Kolb, 1996). It is precisely these cognitive processes that learners use when presented with an analogy to explain a new topic.

Procedure

The investigator explained the purpose and methodology of the study to the Chair of Sciences for Health Programs, the Director of Dental Hygiene, and to the individual anatomy and physiology and dental hygiene instructors to obtain their permission to use volunteers from their classes for this study. The investigator explained the

purpose of the study to the students who agreed to participate. After receiving their Informed Consent Forms, students scheduled appointments to take the Kolb Learning Style Inventory (LSI). The investigator determined their primary learning styles (PLS).

Once the students completed the LSI, the instructor administered a pretest on arterial blood gas interpretation. The pretest consisted of 11 recall questions and of 14 questions that required problem-solving skills. Cronbach alpha reliability analyses were performed for the two types of questions contained within the pretest and showed that students had no prior knowledge of the material and randomly selected answers on the pretest. After a minimum of 1 week from the date of pretest administration, students who preferred concrete learning experiences received either instructional packets that used a non-analogical (mathematical) approach to convey the topic of arterial blood gas interpretation or packets that used visual analogies. If the last four digits of a student's social security number totaled to an even number, the student received a packet using the visual analogy approach. If the last four digits of a student's social security number totaled to an odd number, the student received a packet using the non-analogical (mathematical) approach. The identical procedure was used for students who favored abstract conceptualization as their PLS. Both packets covered the topics of carbon dioxide production, alveolar ventilation, oxygenation, factors

influencing the partial pressure of arterial carbon dioxide ($PaCO_2$), and blood pH. Students were allowed as much time as they needed to review the packets. A posttest was then administered. This approach prevented students from sharing the results of their packets with other participants, a threat to the validity of the study. After completing the posttest, each participant received an information sheet on the Kolb LSI (Appendix E).

Analyses

The interaction between learning styles and packet types was investigated for the two types of questions (problem-solving and simple recall). Two separate analyses of variance (ANOVA) were performed, one for recall questions and one for questions requiring problem solving. ANOVAs were performed in order to compare the means students attained on the examination following manipulation of a single treatment variable (packet type) and to determine whether the differences noted in means were due to systematic effects of the treatment or occurred by chance. F values were calculated for students' primary learning styles, treatment, and primary learning style/treatment interactions.

Summary

This study was designed to determine if a student's primary learning style interacts with instructional packet type to enhance the

student's recall of factual information and/or improve his or her problem-solving skills. This study used the following methodology.

Step 1. Students completed Kolb's Learning Style Inventory.

Step 2. Students took a pretest to determine if they possessed any prior knowledge in the area of blood gas analysis.

Step 3. On the basis of the last four digits of their social security numbers, students received either the visual analogy packet or the mathematics packet as the experimental treatment.

Step 4. Students took a posttest to assess their recall and problem solving skills relating to information contained within the instructional packets.

Step 5. Two separate ANOVA tests were performed, one for recall questions and one for questions requiring problem solving. Interactions between primary learning styles and packet types were investigated.

CHAPTER 4
RESULTS AND ANALYSIS

Introduction

This study was designed to determine whether a participant's primary learning style affects his or her ability to learn from a particular instructional packet type and whether these interactions influence his or her performance on recall questions and questions requiring problem-solving abilities. Primary learning style (PSL) was used as a between subjects attribute variable with two types, concrete experience and abstract conceptualization (Smith & Kolb, 1996). Instructional packet type was manipulated as a between-subjects experimental condition with two types, visual analogies and mathematical formulas.

Results

The experiment was conducted and data were collected as outlined in the previous chapter. Table 4-1 reports the group means and standard deviations on recall and problem-solving questions for all gender/treatment combinations (males/visual analogies, males/mathematical formulas, females/visual analogies, and

females/mathematical formulas). The data were analyzed using two separate ANOVA tests.

Table 4-1

Group Means and Standard Deviations on Recall and Problem-Solving Questions

		Recall		Problem Solving	
Group	N	Mean	Std. Dev.	Mean	Std. Dev.
VA	44	5.73	1.87	7.59	1.90
MA	31	5.97	2.29	6.68	2.73
M	18	6.94	2.13	8.00	2.79
F	57	5.47	1.90	6.96	2.10
VA/M	10	6.20	1.75	7.60	2.12
VA/F	34	5.59	1.91	7.59	1.86
MA/M	8	7.88	2.30	8.50	3.55
MA/F	23	5.30	1.92	6.04	2.12
C/M	4	7.75	1.89	6.25	2.22
C/F	28	5.25	1.88	7.18	2.09
A/M	14	6.71	2.20	8.50	2.79
A/F	29	5.69	1.93	6.76	2.12
VA/C/M	2	8.50	0.71	5.50	2.12
VA/C/F	17	5.12	1.80	7.35	1.97
VA/A/M	8	5.63	1.41	8.13	1.89
VA/A/F	17	6.06	1.95	7.82	1.78

(Table 4-1—continues)

Table 4-1—Continued

Group	N	Recall		Problem Solving	
		Mean	Std. Dev.	Mean	Std. Dev.
MA/C/M	2	7.00	2.83	7.00	2.83
MA/C/F	11	5.45	2.07	6.91	2.34
MA/A/M	6	8.17	2.32	9.00	3.85
MA/A/F	12	5.17	1.85	5.25	1.60

Note: VA = Visual Analogy, MA = Mathematical Formula. M = Male, F = Female, C = Concrete, A = Abstract

The first ANOVA analyzed the interaction between primary learning style and instructional packet type (treatment) as it affects performance on recall types of questions. The results are reported as a source table in Table 4-2. The R-squared for the dependent variable (performance on recall questions) and Treatment x Primary Learning Style interaction was equal to 0.016. The report of results reviews the null hypothesis tested.

Table 4-2

Analysis of Variance Summary Table—Recall Questions

Source	SS	df	MS	F	Pr>F
Treatment	0.962	1	0.962	0.22	0.6369
Primary Learning Style (PLS)	3.765	1	3.765	0.88	0.3514
Treatment x PLS	0.003	1	0.003	0.00	0.9773
Error	303.846	71	4.280		

The Treatment x PLS interaction was removed from the statistical model and the results reported as a source table in Table 4-3. The R-squared was equal to 0.016. Scores on tests of recall were not affected by treatment or PLS.

Table 4-3

Analysis of Variance Summary Table—Recall Questions without Treatment x PLS Interaction

Source	SS	df	MS	F	Pr>F
Treatment	1.002	1	1.002	0.24	0.6275
Primary Learning Style (PLS)	3.845	1	3.845	0.91	0.3514
Error	303.850	72	4.220		

Hypothesis 1 stated that mean outcome scores on examinations testing the recall of abstract concepts do not differ due to the interaction of treatment and learning style. The analysis of variance produced an F value of 0.00 for this interaction that was not statistically significant at the .05 alpha level. The null hypothesis was not rejected. The interaction between treatment and primary learning style did not influence the recall of abstract concepts.

The second test of ANOVA analyzed the interactions between primary learning style and treatment as they affect performance on questions requiring problem-solving skills. These results are reported as a source table in Table 4-4. The R-squared for the dependent variable (performance on problem solving questions) and Treatment x

Primary Learning Style interaction was equal to 0.06. The report of results reviews the null hypothesis tested.

Table 4-4

Analysis of Variance Summary Table—Problem-Solving Questions

Source	SS	df	MS	F	Pr>F
Treatment	12.165	1	12.165	2.34	0.1309
Primary Learning Style (PLS)	0.511	1	0.511	0.10	0.7551
Treatment x PLS	6.240	1	6.240	1.20	0.2774
Error	369.789	71	5.208		

The Treatment x PLS interaction was removed from the statistical model and the results reported as a source table in Table 4-5. The R-squared was equal to 0.042. Scores on tests of problem-solving performance were not affected by instructional packet type or PLS.

Table 4-5

Analysis of Variance Summary Table—Problem-Solving Questions without Treatment x PLS Interaction

Source	SS	df	MS	F	Pr>F
Treatment	15.288	1	15.288	2.93	0.0914
Primary Learning Style (PLS)	1.381	1	1.381	0.26	0.6086
Error	376.029	72	5.223		

Hypothesis 2 stated that mean outcome scores on examinations testing problem-solving performance on questions relating to abstract concepts do not differ due to the interaction of treatment and learning style. The analysis of variance produced an F value of 1.20 for this interaction that was not statistically significant at the .05 alpha level. The null hypothesis was not rejected. The interaction between primary learning style and instructional packet type did not influence the performance on questions requiring problem-solving strategies.

Additional Findings

Although not proposed in the original design of the study, analyses of the interactions among treatment, learning style, and gender were explored, because gender-related differences in subjects' performances on recall and problem-solving questions were noted. Additional ANOVAs were performed that included interactions between treatment and gender, learning style and gender, and treatment and learning style. The three-way interaction among treatment, learning style, and gender also was explored. The results for recall-based questions are reported as source table and are discussed separately.

Neither Treatment x Gender, Primary Learning Style x Gender, or Treatment x Primary Learning Style interaction for the ANOVA of effects on recall performance reported in Table 4-6 was significant at the .05 alpha level. However, the three-way interaction between

Treatment x Primary Learning Style x Gender was significant at the .05 alpha level.

The R-squared for the dependent variable (performance on recall questions) and Treatment x Primary Learning Styles, Primary Learning Style x Gender, Treatment x Primary Learning Styles, and Treatment x Primary Learning Styles x Gender interactions reported as an ANOVA source table in Table 4-6, was equal to 0.22. Recall performance was affected by the eight combinations of variables. On the basis of these findings, the least square means were calculated for the eight combinations of variables and multiple comparisons were performed and are reported in Table 4-7 and Table 4-8.

Table 4-6

Analysis of Variance Summary Table—Recall Questions Including Treatment x Gender, PLS x Gender, Treatment x PLS and Treatment x PLS x Gender Interactions

Source	SS	df	MS	F	Pr>F
Treatment	0.149	1	0.149	0.04	0.8396
PLS	0.703	1	0.703	0.19	0.6607
Gender	35.464	1	35.464	9.81	0.0026
Treatment x Gender	1.610	1	1.610	0.45	0.5069
PLS x Gender	3.522	1	3.522	0.97	0.3273
Treatment x PLS	4.996	1	4.996	1.38	0.2440
Treatment x PLS x Gender	17.543	1	17.543	4.85	0.0311
Error	242.308	67	3.617		

Table 4-7

Least Square (LS) Mean Data for Treatment/PLS/Gender Combinations on Recall Questions

TRT	PLS	Gender	LS Mean	Standard Error	Number of Subjects	LS Mean #
VA	Concrete	M	8.500	1.345	2	1
VA	Concrete	F	5.118	0.461	17	2
VA	Abstract	M	5.625	0.672	8	3
VA	Abstract	F	6.059	0.461	17	4
Math	Concrete	M	7.000	1.345	2	5
Math	Concrete	F	5.455	0.573	11	6
Math	Abstract	M	8.167	0.776	6	7
Math	Abstract	F	5.167	0.549	12	8

Note. VA = Visual analogies, Math = Mathematical formula, M = Males, and F = Females.

Table 4-8

Pair-Wise Comparisons of Least Square (LS) Means (Treatment/PLS/Gender) and Probabilities that LS Means are Equal at Alpha = .05

i/j	1	2	3	4	5	6	7	8
1	--	--	--	--	--	--	--	--
2	0.020	--	--	--	--	--	--	--
3	0.060	0.536	--	--	--	--	--	--
4	0.091	0.154	0.596	--	--	--	--	--
5	0.433	0.190	0.364	0.510	--	--	--	--
6	0.041	0.649	0.848	0.415	0.294	--	--	--
7	0.831	0.001	0.016	0.023	0.455	0.007	--	--
8	0.025	0.946	0.599	0.218	0.211	0.718	0.002	--

Similar analyses for the problem-solving questions were performed. The results for questions requiring problem solving are reported as source tables in Table 4-9, Table 4-10, and Table 4-11and are discussed separately.

Table 4-9

Analysis of Variance Summary Table—Problem-Solving Questions Including Treatment x Gender, PLS x Gender, Treatment x PLS, and Treatment x PLS x Gender Interactions

Source	SS	df	MS	F	Pr>F
Treatment	0.261	1	0.261	0.06	0.8122
PLS	7.458	1	7.458	1.63	0.2064
Gender	3.310	1	3.310	0.72	0.3983
Treatment x Gender	18.362	1	18.362	4.01	0.0493
PLS x Gender	21.342	1	21.342	4.66	0.0345
Treatment x PLS	4.792	1	4.792	1.05	0.3101
Treatment x PLS x Gender	1.430	1	1.430	0.31	0.5782
Error	306.887	67	4.580		

The R-squared for the dependent variable (performance on questions requiring problem solving) and Treatment x Gender, Primary Learning Style x Gender, Treatment x Primary Learning Style, and Treatment x Primary Learning Style x Gender interactions reported as an ANOVA source table in Table 4-9 was equal to 0.22. The interactions between Treatment x Gender and Primary Learning Style x Gender were significant at the .05 alpha level. On the basis of the data reported in Table 4.9, the Treatment x Primary Learning Style and Treatment x Primary Learning Style x Gender interactions were removed from the statistical model. The results are reported as an ANOVA source table in Table 4-10. The R-squared for the dependent variable (performance

on questions requiring problem solving) and Treatment x Gender and Primary Learning Style x Gender interactions reported as an ANOVA source table in Table 4-10, was equal to 0.178. Based on the results reported in Table 4-10, there was a significant interaction between treatment and gender and primary learning style and gender at the .05 alpha level.

Table 4-10

Analysis of Variance Summary Table—Problem-Solving Questions Including Treatment x Gender and PLS x Gender Interactions

Source	SS	df	MS	F	Pr>F
Treatment	0.906	1	0.906	0.19	0.6613
Primary Learning Style (PLS)	9.530	1	9.530	2.04	0.1580
Gender	3.535	1	3.535	0.76	0.3877
Treatment x Gender	21.809	1	21.809	4.66	0.0343
PLS x Gender	18.701	1	18.701	4.00	0.0495
Error	322.728	69	4.677		

The relationships between treatment and gender and primary learning style and gender were explored by comparisons of least squares means for participant performance on problem-solving questions. Table 4-11 presents the least square means and standard errors for the least square means for the four treatment/gender combinations. A pair-wise comparison of least square means was

conducted at an alpha of .05. The probabilities that the means are equal for each of these pair-wise comparisons are presented in Table 4-12.

Table 4-11

Least Square (LS) Mean Data for Treatment/Gender Combinations on Problem-Solving Questions

Treatment	Gender	LS Mean	Standard Error	LS Mean #
Visuals	Male	6.90	0.777	1
Visuals	Female	7.59	0.371	2
Math	Male	7.92	0.824	3
Math	Female	6.05	0.451	4

Table 4-12

Pair-Wise Comparisons of Least Square (LS) Means (Treatment/Gender) and Probabilities that LS Means are Equal at Alpha = .05

i/j	1	2	3	4
1	--	--	--	--
2	0.4289	--	--	--
3	0.3262	0.7152	--	--
4	0.3466	0.0105	0.0508	--

The relationships between primary learning style and gender were explored by comparisons of least squares means for performance on problem-solving questions.

Table 4-13 presents the least square means and standard errors for the least square means for the four primary learning style/gender combinations. A pair-wise comparison of the least square means was conducted at an alpha of .05. The probabilities that the means are equal for each of these pair-wise comparisons are presented in Table 4.14.

Table 4-13

Least Square (LS) Mean Scores and Standard Errors Data for Primary Learning Style/Gender Combinations on Problem-Solving Questions

Treatment	Gender	LS Mean	Standard Error	LS Mean #
Concrete	Male	6.25	1.081	1
Concrete	Female	7.01	0.413	2
Abstract	Male	8.57	0.583	3
Abstract	Female	6.63	0.405	4

Table 4-14

Pair-Wise Comparisons of Least Square (LS) Means (Primary Learning Style x Gender) and Probabilities that LS Means are Equal at Alpha = .05

i/j	1	2	3	4
1	--	--	--	--
2	0.5115	--	--	--
3	0.0628	0.0326	--	--
4	0.7456	0.5009	0.0077	--

Summary

To summarize, the analyses of data collected for this study resulted in the following findings. There were no statistically significant interactions between PLS and instructional packet types and performances on recall questions or questions requiring problem-solving abilities. For questions requiring simple recall, a significant three-way interaction was found for Treatment x Primary Learning Style x Gender. There were significant interactions between instructional packet type (treatment) and gender and primary learning style and gender on questions requiring problem-solving abilities.

This study was designed to determine whether a learner's primary learning style affects his or her ability to learn from an instructional packet type and whether these interactions influence his or her performance on recall questions and questions requiring problem-solving abilities. What are the implications of these results for the design of instructional materials that will most facilitate the learning of students who differ in learning style and gender? Are animations a more effective method of presenting dynamic processes than a series of static images? Are actual scores on the abstract conceptualization/concrete experience continuum more predictive of learning benefits than the qualitative categorizations of abstract or concrete primary learning styles? These questions are addressed in the final chapter.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

Introduction

The purpose of this study was to investigate whether material presented in the form of mathematical expressions or visual analogies interact with an individual's learning preference to enhance recall and problem solving. Interactions between instructional packet type and learners' primary learning styles (PLS) were investigated on two types of multiple choice questions, those requiring simple recall of information and those requiring problem solving.

The experimental model consisted of two separate 2 x 2 designs. The two categories were primary learning style (concrete experience or abstract conceptualization) and instructional packet type (mathematical formulas or visual analogies). The interaction between primary learning styles and learning packet types was investigated for two types of questions (recall and problem solving). Two separate analyses of variance were performed, one for recall questions and one for questions requiring problem solving. After the collection of the data, additional interactions between treatment and gender, primary learning style and gender, and treatment and primary learning style, and gender were explored.

To implement this study, students enrolled in anatomy and physiology courses and dental hygiene students who had completed anatomy and physiology were chosen as the population from which the sample was chosen. The Kolb Learning Style Inventory (LSI) was used to determine the students' PLS. Materials were developed to present important concepts in blood gas interpretation using either mathematical formulas or visual analogies. To determine if participants had any prior knowledge relating to blood gas interpretation, a pretest on the subject of blood gas analysis was developed and administered that contained 11 recall questions and 14 questions requiring problem-solving skills. The pretest was administered immediately after participants completed the LSI. After a minimum of 1 week, participants were randomly assigned to one of the two types of instructional packets. After completing the packets, participants took a posttest that was identical to the pretest. Expert opinions were used to substantiate the equivalency of content contained in the mathematical packets and visual analogy packets. In addition, expert opinion was used to substantiate the categorization of test questions as either problem solving or recall in nature.

Findings

The study was implemented, data were collected, and the data were analyzed in terms of the stated hypotheses. The research questions had been stated by the following null hypotheses:

Hypothesis 1. Mean outcome scores on examinations testing the recall of abstract concepts do not differ due to the interaction of treatment and learning style. This hypothesis was not rejected.

Hypothesis 2. Mean outcome scores on examinations testing problem-solving performance on questions relating to abstract concepts do not differ due to the interaction of treatment and learning style. This hypothesis was not rejected.

Specifically, no interactions were found between primary learning style (concrete experience or abstract conceptualization) and instructional treatment (analogical or mathematical packet) on participants' performances on recall and problem-solving questions.

Discussion

Although none of the null hypotheses were rejected, interactions were noted for both recall and problem-solving questions. A significant three-way interaction between Treatment x Primary Learning Style x Gender was found at an alpha = .05. After controlling for family error rates, a significant difference in least square means was found at an alpha level of .05 (.05/28 = .002). Pair-wise comparisons of least square mean scores showed that males with abstract primary learning styles who received mathematical packets scored significantly higher than females with concrete primary learning styles who received visual analogy packets.

Significant interactions were found between treatment and gender and primary learning style and gender relating to performances on problem-solving questions. Treatment and gender and primary learning style and gender interactions had significance at an alpha = .05. Two sets of pair-wise comparisons of least square means were conducted to determine significant differences between subjects' performances on questions requiring problem-solving skills.

The first set of pair-wise comparisons compared least square means for the four combinations of treatment and gender (visuals/males, visuals/females, math/males, and math/females). After controlling for family error rates, no significant differences in least square means were found at an alpha level of .05 (.05/6 = .0083).

The second set of pair-wise comparisons compared least square means for the four combinations of primary learning style and gender (concrete/males, concrete/females, abstract/males, and abstract/females). After controlling for family error rates, a significant difference in least square means were found at an alpha level of .05 (.05/6 = .0083) between abstract males and abstract females.

These data show that males with abstract learning styles performed significantly better than females with abstract learning styles on examination questions that required problem-solving skills. Although a treatment x gender effect was noted, a comparison of least

square means did not reveal a significant difference in performances on questions requiring problem-solving skills.

The better problem-solving performance by males who favor abstract conceptualization over females who favor abstract conceptualization is difficult to explain solely on the basis of this study. Enns (1993), in her review of literature related to learning styles and gender differences, determined that the characteristics of reflection and abstraction are traditionally associated with the masculine gender, whereas concrete experience and active experimentation are more closely aligned with the female gender. Seventy-eight percent of male subjects who participated in this study had a preference for abstract conceptualization as their favored mode of obtaining new information, whereas only 50% of the females displayed a preference for abstract conceptualization. Enns' findings would explain the gender-related distributions of primary learning styles observed in this study, but not why females who prefer abstract conceptualization would perform less well than their male counterparts.

Although males who received the mathematics packet had a least square mean nearly 25% higher than females receiving the mathematics packet, the results were not significant statistically. Lack of statistical significance may be due to the small number of males

participating in this study (N=18, with eight males receiving the mathematics packet).

Furthermore, females who received the visual analogy packet had a least square mean approximately 20% higher than females receiving the mathematics packet. Once again, the results were not statistically significant and may be due to disparities in the number of females receiving each of the treatments (34 females received the visual analogy packet whereas only 23 females received the mathematics packet). Nevertheless, the results are suggestive of gender/treatment interactions that were confirmed in the ANOVA.

Implications

These results add to the knowledge base used by educators in the design of instructional materials. Although primary learning style (PLS) and instructional treatment interactions were not statistically significant, interactions did occur between gender and treatment and learning style and gender. Whereas this study did not show that learners with concrete primary learning styles would benefit from the use of visual analogies, or that learners favoring abstract conceptualization would benefit with either visual analogies or mathematical formulas, the study did show that gender and treatment did interact significantly. Primary learning styles and gender did interact significantly as well. Awareness of such interactions heightens the need for the inclusion of multiple strategies in the delivery of

instruction. Illustrating abstract concepts through the use of visual and/or verbal analogies may result in greater learning gains for women, especially when compared to mathematical formulas. Even though the number of male subjects in this study was small (N=18), males appear to perform equally well on examinations testing problem-solving skills, regardless of whether they receive the material in the analogical or mathematical formats. In an attempt to apply information gained about learners' preferred styles to instructional strategies, Lockitt (1997) identified learning activities that would appeal to learners with the attributes identified by the LSI. However, Tendy and Geiser (1997) noted that considerable debate still exists on whether instruction should focus on matching a learner's preferred style or altering it.

Recommendations for Future Research

One method of improving the power of this study would be to use an appropriate covariant. Cronbach alpha reliability analyses were performed for the two types of questions contained within the pretest and showed that students had no prior knowledge of the material and randomly selected answers on the pretest. Consequently, the pretest could not be used as a covariant. Another ability indicator, such as quantitative achievement scores on the ACT, SAT, or computerized placement test (CPT), or students' mathematics GPAs, could serve as appropriate covariants.

Also, the randomization technique used to assign packet types that was based on the sum of the last four digits of the student's social security number, resulted in a disparity in the number of analogical and mathematical (logical) packets assigned (44 and 31 respectively). A technique such as having a subject flip a coin on entering the room to determine whether he or she receives the visual analogy packet or the mathematics packet and then assigning the other packet type to the next subject entering the room, would eliminate this problem. However, the independence of packet assignment may be compromised by the coin-flip approach and adversely affect the validity of the study.

The visual-analogy instructional packet used a series of static images to convey the relationships between independent and dependent variables. Images of pointing hands and dashed lines indicating initial and final levels of independent variables were used to highlight alterations discussed in the text (see Appendix B). However, the process of homeostasis is inherently a dynamic, continuous phenomenon. Rather than occurring in discrete steps, infinitesimal alterations in carbon dioxide production and/or alveolar ventilation result in an infinite number of possible carbon dioxide levels in the arterial blood. The concept of homeostasis may therefore be conveyed more accurately if animation is used to show the interactions between independent variables and their effects on a dependent variable. Using

an interactive animation that would allow the subject to vary the flow of water into the tub (carbon dioxide production) and/or alter the flow of water out of the tub (alveolar ventilation) may have enhanced concept attainment. A similar animation could be used to show the relationship between alterations in $PaCO_2$ and/or bicarbonate levels (HCO_3) and the effect of these alterations on blood pH. The use of animations may support a cognitive process that is different from the cognitive process supported by static, visual analogies. Although each presentation format (static images versus animations) could use attention focusing mechanisms, they would still represent different instructional methods (Clark, 1994).

An additional strategy that may improve performance on the examination would be to refer to the analogies used in the instructional packets during the examination. Gick and Holyoak (1980, 1983) found that investigator-supplied analogies increased the likelihood that learners would arrive at a creative solution to a problem (Duncker's radiation problem, see p. 35). However, without a hint from the investigators to use the story, Gick and Holyoak found that most learners did not spontaneously use the analogy to solve the problem. The current study could be modified to determine if explicit references to the visual analogies would influence participants' performances on the examination. Rather than comparing learning gains from visual analogies and mathematical formulas, concrete learners could receive

the same treatment (visual analogies) and take one of two versions of a posttest, one with references to the analogies and one examination without the references. Lack of reference to the analogies used in the visual analogy packet was not viewed as a limitation for this study due to the short time delay between treatment and posttest (all participants took the posttest immediately after the treatment). Consequently, short-term memory should have allowed the participants to remember the visual analogies. In addition, Gick and Holyoak (1980) never stated that the analog to their multiple small armies was the radiation beam or that the analog to the castle was the large abdominal tumor. In contrast, the relationships between analogs and targets were explicitly stated in the visual analogy packets used in this study.

The current study considered primary learning styles (PLS) qualitatively as concrete experience (CE) or abstract conceptualization (AC). A more quantitative approach could be adopted in which the subject's actual value on the AC—CE continuum would be used in the analysis. Conceivably, only individuals with strong preferences for concrete experiences may benefit from the use of visual analogies. Figure 5-1 illustrates this concept. For example, a subject with an AC—CE score of +3 (very close to the intersection of the concrete-abstract and active experimentation-reflective observation continua) may have equal preferences for concrete experiences and abstract

conceptualization. A subject with an AC—CE score of –27, in contrast, would have a much stronger preference for concrete experiences and, conceivably, benefit from the visual analogies to a greater degree. Ruble and Stout (1994) raised a similar concern for the characterization of both subjects as having concrete experiences as their primary learning style.

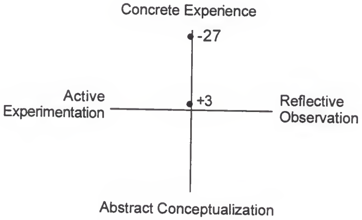


Figure 5-1. Mild (+3) and Strong (-27) Preferences for Concrete Experiences Compared to Abstract Conceptualization

A major concern that arose during this study involved the motivation of the individuals who volunteered to participate in the research. Analysis of the data revealed that 21 of the participants scored lower on the posttest than they did on the pretest, even though a Cronbach alpha run on the pretest showed that participants randomly selected their answers. Guessing was permitted because the participants had no prior exposure to the subject matter. However, on the posttest, six participants selected answer "c," "d," or "e" on a multiple-choice question that had only two choices. Evidently, these

participants did not read the question and distracters prior to marking their response sheets. One participant repeated the sequence of "a," "b," "c," "d," and "e" as answers from the beginning to the end the response sheet. Once again, the conclusion could be that the subject did not make a concerted effort to answer the questions carefully. As stipulated in the informed consent form, participation in the research was voluntary. However, the validity and reliability of the conclusions reached in this study would have been enhanced by sincere efforts on the parts of the subjects. Obtaining the sample from a population of students who had to perform their own research studies may increase their motivation to perform to the best of their abilities.

This study only evaluated short-term recall of factual information and problem-solving ability related to arterial blood gas interpretation. Newby et al. (1995) found that retention scores were better for students receiving analogies than students who did not receive the analogies. Although the visual analogies did not result in significant learning gains in terms of short-term performance on the examination used in this study, long-term learning may be enhanced due to the dual encoding of visuals proposed by Peeck (1974) and Paivio (1979).

Summary

This study investigated learning gains based on the interactions between students' primary learning styles (concrete experience and abstract conceptualization) and instructional packet types (visual

analogies and mathematical formulas). The sample for this study was 75 students enrolled in introductory anatomy and physiology courses at a middle-sized community college located in north central Florida and dental hygiene students who had completed college-level anatomy and physiology coursework. The experimental model consisted of two separate, 2 x 2 designs. The two categories were primary learning style (concrete experience or abstract conceptualization) and instructional packet type (mathematical formulas or visual analogies). The interaction between primary learning styles and packet types was investigated for two types of questions (problem solving or simple recall). Two separate analyses of variance were performed, one for recall questions and one for questions requiring problem-solving skills.

There were no statistically significant interactions between students' primary learning styles (PLS) and instructional packet types. There were no statistically significant interactions between PLS and instructional packet types and performances on recall questions or questions requiring problem-solving abilities. A significant three-way interaction was found for instructional packet type (treatment), primary learning style, and gender for recall questions. There were significant interactions between treatment and gender and primary learning style and gender on questions requiring problem-solving abilities.

In conclusion, primary learning styles and instructional treatments do not interact to affect performances on recall questions

and questions requiring problem-solving strategies. Instructional packet type (treatment), primary learning style, and gender interact to affect students' performances on recall questions. The results from this study show that instructional treatments do interact with gender to affect performances on questions requiring problem-solving skills. Furthermore, performances on questions requiring problem-solving skills were affected by primary learning style and gender interactions.

Conclusions from this study were restricted to the variables manipulated in the study and limited to the populations represented by the sample participating in the study. Further research questions were presented based on findings from this study and serve as directions for future research.

APPENDIX A
INFORMED CONSENT FORM

Informed Consent

Protocol Title: Differential Impact On Recall And Problem Solving Performances Of Concrete And Abstract Thinkers Resulting From Analogical Versus Logical Representations Of Theoretical Concepts

Please read this consent document carefully before you decide to participate in this study.

Purpose of the research study:
I am studying whether students' ways of thinking affect how useful visual analogies will be on their learning of new material. A visual analogy is a way of presenting new information by comparing it with illustrations of common objects or processes. Because they already understand the common objects or processes, this knowledge should help them learn the new information. You are being asked to take the examination that will be used in the study in order to test the examination's reliability.

What you will be asked to do in the study:
If you agree to be in this study, you will be given a test on arterial blood gas interpretation. Once you complete the test, you will return it to your instructor. Your name will not be used.

Total time required:
15 minutes.

Risks and Benefits:
There is no risk or physical discomfort associated with this study. There are no benefits to you for participation.

Compensation:
You will not receive compensation for participating in this research.

Confidentiality:
Your identity will be kept confidential to the extent provided by law.

Voluntary participation:
Your participation in this study is completely voluntary. There is no penalty for not participating. Your decision to participate or not participate in this study will not affect your grade in any course.

Right to withdraw from the study:
You have the right to withdraw from the study at anytime without consequence.

Whom to contact if you have questions about the study:
David N. Yonutas, MS, RRT; phone number: (352) 375-6924

Whom to contact about your rights as a research participant in the study:
UFIRB Office, Box 112250, University of Florida, Gainesville, FL 32611-2250; phone number: (352) 392-0433.

Agreement:
I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description.

Participant: ______________________________ Date: __________

Principal Investigator: ________________________ Date: __________

APPENDIX B
PACKET 1: ANALOGICAL PACKET

Blood Gas Analysis

A Dripping Faucet and Draining Tub

Imagine a faucet, a tub of water, and a drain. In **Figure 1**, the amount of water entering the tub i s exactly equal to the amount of water exiting the tub through the drain. The level of water in the tub would consequently remain constant and is indicated by the pointing hand. This is the baseline condition.

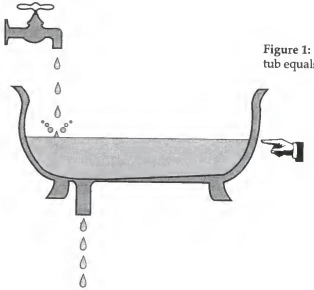


Figure 1: Baseline condition - Water exiting tub equals water entering tub

If the drain becomes clogged, resulting in less water flowing out of the tub, the level of water will increase (**Figure 2**). The shadow pointing hand represents the original water level.

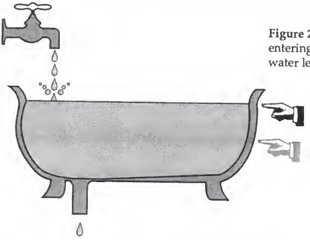


Figure 2: Less water exiting tub than water entering tub resulting, in an increase in the water level within the tub.

In **Figure 2**, increasing the flow of water into the tub without altering the flow of water out of the tub would also increase the level of water.

If the handle of the faucet is turned counterclockwise, more water exits the tub than enters it and the level of water within the tub will decrease (see **Figure 3**). Similarly, if more water exited the tub without decreasing the flow of water from the faucet, the water level would fall as well.

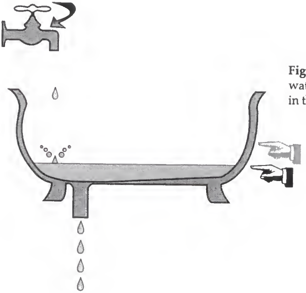


Figure 3: Less water entering the tub than water exiting the tub results in a decrease in the water level within the tub.

Determinants of $PaCO_2$

In terms of blood gas analysis, the level of water within the tub represents $PaCO_2$, or the partial pressure of carbon dioxide in the arterial blood. The amount of water coming from the faucet is equivalent to carbon dioxide production (or $\dot{V}CO_2$) and the amount of water leaving the tub is analogous to alveolar ventilation ($\dot{V}_A$), resulting in carbon dioxide elimination (See Table 1, next page). **Figure 4** illustrates this concept.

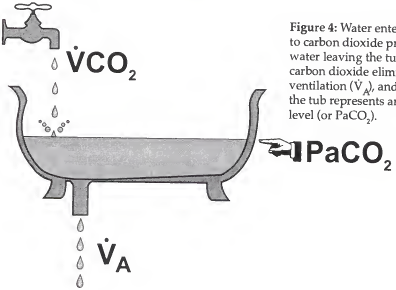


Figure 4: Water entering tub is equivalent to carbon dioxide production ($\dot{V}CO_2$), water leaving the tub is equivalent to carbon dioxide elimination due to alveolar ventilation ($\dot{V}_A$), and the water level within the tub represents arterial carbon dioxide level (or $PaCO_2$).

As with the tub, increases in carbon dioxide production without a corresponding increase in alveolar ventilation would result in an increase in $PaCO_2$, just as increases in water entering the tub without changes in water outflow would increase the level of water in the tub. Increases in alveolar ventilation in the absence of increased carbon dioxide production would cause $PaCO_2$ to fall, just as increases in water leaving the tub without changes in the flow of water entering would decrease the level of water in the tub.

If carbon dioxide production is balanced by the appropriate amount of alveolar ventilation, the $PaCO_2$ will equal 35-45 mm Hg.

Table 1: Tub and Faucet Analogy and Determinants of $PaCO_2$

Component of Tub and Faucet Analogy	**$PaCO_2$ and It's Determinants**
Water dripping into tub	Carbon dioxide production
Level of water in the tub	Carbon dioxide levels in arterial blood ($PaCO_2$)
Water flowing out of the tub	Alveolar ventilation

An Additional Analogy

Now imagine that you have an internal "Comfort Balance." This balance looks like the one in **Figure 5**.

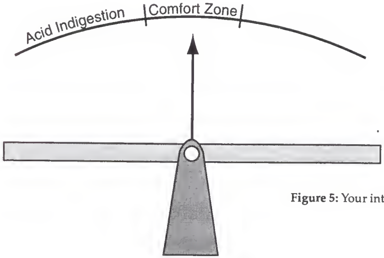


Figure 5: Your internal "Comfort Scale."

With everyday stress, you have the equivalent of one jalepeno pepper in your stomach. This is buffered by naturally occurring buffers (represented by an antacid tablet). This keeps your balance in the "comfort zone." (Figure 6).

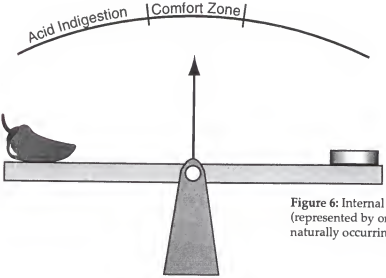


Figure 6: Internal balance of daily stress (represented by one jalepeno pepper) and naturally occurring buffers (antacid tablet).

However, you happen to enjoy eating jalepeno peppers. The only problem is that they give you acid indigestion. Whenever you eat a pepper, it "tilts" your comfort scale into the "Acid Indigestion" area (**Figure 7**).

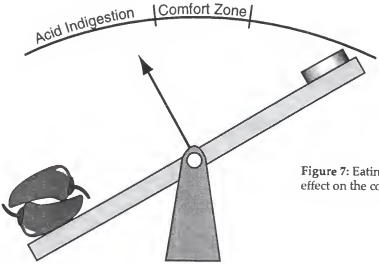


Figure 7: Eating a jalepeno pepper and its effect on the comfort scale.

In order to correct this unpleasant state, you take an antacid. This tilts your comfort scale back into the "Comfort Zone" (**Figure 8**).

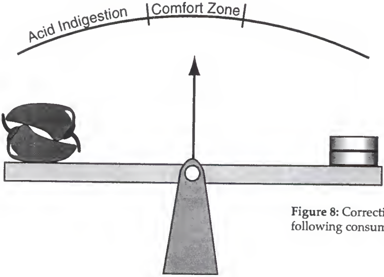


Figure 8: Correction of acid indigestion following consumption of an antacid tablet.

Now that you feel better, you eat an additional pepper which again results in acid indigestion (**Figure 9**).

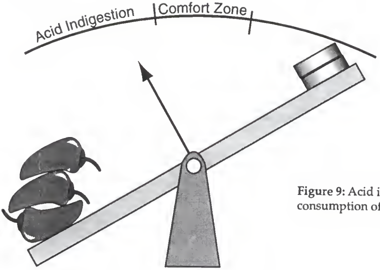


Figure 9: Acid indigestion following consumption of a second jalepeno pepper.

Your only way of correcting this imbalance, is to consume an additional antacid (**Figure 10**).

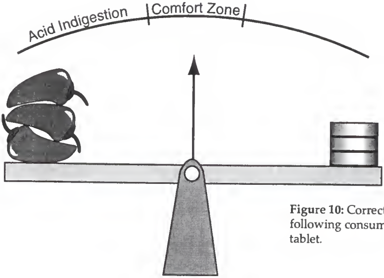


Figure 10: Correction of acid indigestion following consumption of a second antacid tablet.

Notice that there are still two additional peppers present, but their deleterious effects have been neutralized by the two additional antacid tablets. As long as additional peppers are "balanced" by additional antacids, the scale's pointer will be in the "Comfort Zone."

Effect on Acid-Base Balance

The internal comfort balance, jalepeno peppers, and antacid tablets are analogous to the pH of arterial blood, the partial pressure of carbon dioxide ($PaCO_2$) in the arterial blood, and bicarbonate levels within the blood (HCO_3) respectively (Table 2).

Table 2: Equivalency of Comfort Scale Analogy and Arterial Blood Components

Component of Comfort Scale	Component of Arterial Blood
Scale indicating Acid Stomach and Comfort Zone	pH of arterial blood
Jalepeno Peppers	Carbon dioxide levels in arterial blood ($PaCO_2$)
Antacid Tablets	Bicarbonate levels in arterial blood (HCO_3)

Figure 11 illustrates the equivalency of pH, $PaCO_2$, and HCO_3 with our comfort scale. As long as the $PaCO_2$ and HCO_3 levels "balance" each other, the pH will be within normal range (7.35 to 7.45). Normal blood levels of $PaCO_2$ are 35 to 45 mm Hg, while normal blood levels of HCO_3 are 22 to 26 mEq/L.

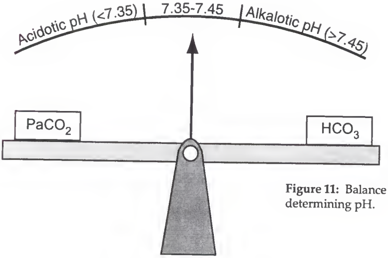


Figure 11: Balance of $PaCO_2$ and HCO_3 determining pH.

If the patient's $PaCO_2$ should rise due to chronic hypoventilation (>45 mm Hg), the pH of the blood will become acidotic (<7.35) as shown in Figure 12 (the original level of PaCO2 is indicated by a dashed line and the new level is indicated by the pointing hand).

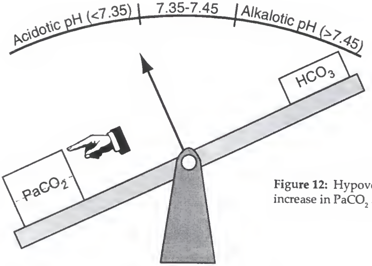
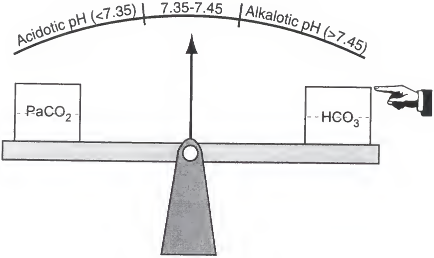


Figure 12: Hypoventilation leading to an increase in $PaCO_2$ and a fall in pH.

In order to return the blood's pH to within normal range with this elevated $PaCO_2$, the kidneys retain bicarbonate. In Figure 13, the new level of HCO_3 necessary to return the pH to normal is indicated by the pointing hand (the original level of HCO_3 is indicated by the dahed line).



Similarly, if an individual hyperventilates for long periods of time (causing his or her $PaCO_2$ to fall below 35 mm Hg) the pH will increase. The kidneys will eliminate HCO_3 in order to return the pH into normal range from an alkalotic pH. Figures 14 illustrates this reduction in $PaCO_2$ (pointing finger) and increase in pH while Figure 15 highlights the drop in HCO_3 to a new, lower level (indicated by pointing finger) and reestablishment of normal pH.

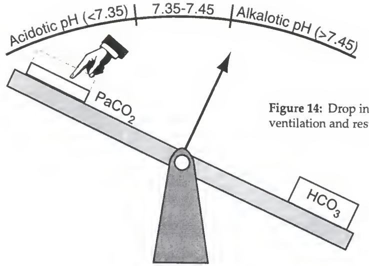


Figure 14: Drop in $PaCO_2$ due to hyperventilation and resulting alkalotic pH.

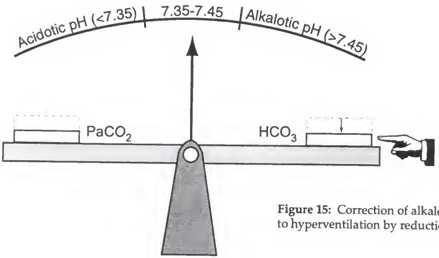


Figure 15: Correction of alkalotic pH due to hyperventilation by reduction of HCO_3.

Relationship of Acid-Base Balance and Disease; Complete versus Partial Compensation

Respiratory diseases such as chronic bronchitis and cystic fibrosis may cause $PaCO_2$ to rise above normal (> 45 mm Hg). This *increase* in $PaCO_2$ is termed a *respiratory acidosis* or *alveolar hypoventilation*. As a result of this elevated carbon dioxide in the blood, the pH will fall below normal (< 7.35). (This is similar to eating additional peppers without taking additional antacids.) As long as $PaCO_2$ levels remain elevated, the only method the body has of correcting the acidotic pH is to retain bicarbonate (analogous to eating antacid tablets). If the body's pH returns to within normal range (7.35-7.45), full compensation has occurred. If bicarbonate levels are higher than normal (> 26 mEq/L) but the pH is still below normal (< 7.35), partial compensation has occurred (similar to ingesting only one antacid tablet when two were needed).

In contrast, patients who are in a great deal of pain or who are anxious may have lower than normal $PaCO_2$ values. This *decrease* in $PaCO_2$ is termed a *respiratory alkalosis* or *alveolar hyperventilation.* As a result of this decreased level carbon dioxide in the blood, the pH will increase above normal (>7.45). (This is similar to eliminating a pepper without taking losing any antacid.) As long as $PaCO_2$ levels remain reduced, the only method the body has of correcting the alkalotic pH is to eliminate bicarbonate (analogous to eliminating antacid tablets). If the body's pH returns to within normal range (7.35-7.45), full compensation has occurred. If bicarbonate levels are lower than normal (< 22 mEq/L) but the pH is still above normal (> 7.45), partial compensation has occurred (similar to eliminating only one antacid tablet when two were needed).

Alterations in the metabolic side of the acid/base balance may occur. Diuretic therapy, vomiting, and nasogastric suctioning are examples of conditions which would cause a loss of acid from the body (equivalent to *gaining* antacids or more base). This will cause the balance to shift to an alkalotic pH and cause a metabolic alkalosis. The only way the body can compensate for this loss of acid (or relative gain in base) is to retain carbon dioxide or hypoventilate (gaining more peppers). If the body's pH returns to within normal range (7.35-7.45), full compensation has occurred. If $PaCO_2$ levels are higher than normal (> 45 mm Hg) but the pH is still above normal (> 7.45), partial compensation has occurred (similar to ingesting only one pepper when two were needed).

Finally, conditions such as hyponatremia and anaerobic metabolism would cause an increase in the amount of metabolic acid in the body (equivalent to *losing* antacid tablets). This will cause the balance to shift to an acidotic pH and cause a metabolic acidosis. The only way the body can compensate for this additional acid (or relative loss of base) is to eliminate more carbon dioxide or hyperventilate (losing peppers). If the body's pH returns to within normal range (7.35-7.45), full compensation has occurred. If $PaCO_2$ levels are lower than normal (< 35 mm Hg) but the pH is still below normal (< 7.35), partial compensation has occurred (similar to eliminating only one pepper when two should have been eliminated).

Determining the Primary Condition versus the Compensatory Mechanism

The reader may have a question regarding how the primary condition causing the acid-base imbalance may be distinguished from the compensatory mechanism. **Arterial Blood Gas #1** illustrates this problem:

Arterial Blood Gas #1

pH: 7.36
$PaCO_2$: 58 mm Hg
HCO_3: 33 mEq/L

The question is "What is the primary problem? Does this patient have a respiratory acidosis (alveolar hypoventilation) or a metabolic alkalosis? Certainly, the patient's clinical presentation provides a strong clue. If the patient has a history of chronic bronchitis, then the primary problem would be the respiratory acidosis.

Additionally, the blood gas itself provides another clue. One of the fundamental principles in interpreting arterial blood gas results is that the *body never overcompensates*. For example, if the primary problem was a metabolic alkalosis, then the patient would hypoventilate to compensate and his $PaCO_2$ would rise. However, the patient would not hypoventilate to the extent that the pH would have gone to the low (or acidotic) side of the normal range for pH. A pH between 7.40 and 7.45 would be expected, not one between 7.35 and 7.40.

Arterial Blood Gas #2 is a similar arterial blood gas, only partially compensated:

Arterial Blood Gas #2

pH: 7.34
$PaCO_2$: 58 mm Hg
HCO_3: 30 mEq/L

Note that the $PaCO_2$ and HCO_3 are both out of normal range; however, **Arterial Blood Gas #1** has a normal pH while **Arterial Blood Gas #2** has a pH that remains acidotic.

A Word on Oxygenation

An interpretation of an arterial blood gas would not be complete without consideration of the patient's oxygenation status. The patient's oxygenation status is determined by his or her hemoglobin level (Hb) and saturation (SaO_2), the partial pressure of oxygen in his or her arterial blood (PaO_2), the patient's cardiac output, and the fraction of inspired oxygen (FIO_2). Low levels of oxygen in the arterial blood is termed hypoxemia.

Dr. Barry Shapiro, a well-known pulmonologist, has arbitrarily set the following ranges for mild, moderate, and severe hypoxemia:

If the PaO_2 is between 60-79 mm Hg ....the patient has mild hypoxemia.

If the PaO_2 is between 40-59 mm Hg ....the patient has moderate hypoxemia.

If the PaO_2 is less than 40 mm Hg ....the patient has severe hypoxemia.

If the PaO_2 is greater than 79 mm Hg ....the patient has no hypoxemia.

The practitioner must always consider the patient's Hb levels during interpretation. A low or abnormal Hb may result in inadequate amounts of oxygen in the arterial blood (normal Hb level is approximately 15 gram percents (g%)). Similarly, a low cardiac output may cause inadequate delivery of oxygen to the tissues, even though the PaO_2 and Hb values are normal.

Finally, the practitioner must always consider the FIO_2 during his or her interpretation. A PaO_2 of 90 mm Hg is certainly normal; however, if the patient is receiving an FIO_2 of 0.80, then there would be cause for concern. Multiplying the FIO_2 by 500 will provide a rough approximation of the PaO_2 that should result from a given FIO_2 if the patient DOES NOT have an oxygenation problem.

APPENDIX C

PACKET 2: MATHEMATICAL PACKET

Blood Gas Analysis

Determinants of $PaCO_2$

There are two determinants for the partial pressure of carbon dioxide in arterial blood ($PaCO_2$): the amount of carbon dioxide produced in the body and alveolar ventilation. The relationship between carbon dioxide production, alveolar ventilation, and $PaCO_2$ is shown in **Equation 1**. As long as any changes in carbon dioxide production are balanced by equivalent changes in alveolar ventilation, $PaCO_2$ will remain constant.

$$PaCO_2 = \frac{\dot{V}CO_2}{\dot{V}_A} \times K$$

where:

$PaCO_2$ = arterial level of carbon dioxide
$\dot{V}CO_2$ = carbon dioxide production
$\dot{V}_A$ = alveolar ventilation
K = a constant

Equation 1: Determinants of $PaCO_2$

Equations 2- 3 illustrate how fluctuations in either carbon dioxide production or alveolar ventilation will affect $PaCO_2$.

$$\uparrow PaCO_2 = \frac{\uparrow \dot{V}CO_2}{\dot{V}_A} \times K$$

Equation 2: Increased $PaCO_2$ due to increased carbon dioxide production with constant alveolar ventilation. Note that decreasing alveolar ventilation while keeping production constant would result in a similar increase in $PaCO_2$ levels.

$$\downarrow PaCO_2 = \frac{\dot{V}CO_2}{\uparrow \dot{V}_A} \times K$$

Equation 3: Decreased $PaCO_2$ due to decreased carbon dioxide production and a constant level of alveolar ventilation. Note that a similar fall in $PaCO_2$ would occur if alveolar ventilation increased and carbon dioxide production remained constant.

If carbon dioxide production is balanced by the appropriate amount of alveolar ventilation, the $PaCO_2$ will equal 35-45 mm Hg.

Effect of $PaCO_2$ and HCO_3 on Acid-Base Balance

Carbon dioxide levels affect the pH of the blood. Based on the Henderson-Hasselbach equation, **Equation 4** illustrates the relationship between bicarbonate levels (HCO_3), $PaCO_2$, and pH. As with the determinants of $PaCO_2$, as long as the initial ratio is maintained between bicarbonate and $PaCO_2$, the pH will remain constant.

$$pH \propto \frac{HCO_3}{PaCO_2}$$

Equation 4: Relationship between HCO_3, $PaCO_2$, and pH.

As $PaCO_2$ levels <u>increase</u>, the pH will <u>decrease</u> (**Equation 5**):

$$\downarrow pH \propto \frac{HCO_3}{\uparrow PaCO_2}$$

Equation 5: Increased $PaCO_2$ causing a decrease in pH.

In order to correct this drop in pH, the bicarbonate levels must increase an equivalent amount (**Equation 6**):

$$pH \propto \frac{\uparrow HCO_3}{\uparrow PaCO_2}$$

Equation 6: <u>Increased</u> bicarbonate levels <u>normalizing</u> the pH following an increase in carbon dioxide levels.

If cabon dioxide levels increased even more, the pH would again fall (**Equation 7**):

$$\downarrow pH \propto \frac{\uparrow HCO_3}{\uparrow\uparrow PaCO_2}$$

Equation 7: Further <u>increase</u> in $PaCO_2$ causing an further <u>decrease</u> in pH.

As HCO_3 levels <u>increase</u> further, the pH again may be normal (**Equation 8**):

$$pH \propto \frac{\uparrow\uparrow HCO_3}{\uparrow\uparrow PaCO_2}$$

Equation 8: Increased HCO_3 causing a normalization of pH following an increase in $PaCO_2$.

As long as the $PaCO_2$ and HCO_3 levels are within their respective normal ranges, the pH will be within normal range (7.35 to 7.45). Normal blood levels of $PaCO_2$ are 35 to 45 mm Hg, while normal blood levels of HCO_3 are 22 to 26 mEq/L. If the patient's $PaCO_2$ should rise due to chronic hypoventilation ($PaCO_2$ > 45 mm Hg), the pH of the blood will become acidotic (< 7.35).

In order to return the blood's pH to within normal range with this elevated $PaCO_2$, the kidneys retain bicarbonate. Similarly, if an individual hyperventilates for long periods of time (causing his or her $PaCO_2$ to fall below 35 mm Hg) the pH will increase. The kidneys will eliminate HCO_3 in order to return the pH into normal range from an alkalotic pH.

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Finally, conditions such as hyponatremia and anaerobic metabolism would cause an increase in the amount of metabolic acid in the body. This will cause the acid-base balance to shift to an acidotic pH, resulting in a metabolic acidosis. The only way the body can compensate for this additional acid (or relative loss of base) is to eliminate more carbon dioxide or hyperventilate. If the body's pH returns to within normal range (7.35-7.45), full compensation has occurred. If $PaCO_2$ levels are lower than normal (< 35 mm Hg) but the pH is still below normal (< 7.35), partial compensation has occurred.

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HCO_3: 33 mEq/L

The question is "What is the primary problem? Does this patient have a respiratory acidosis (alveolar hypoventilation) or a metabolic alkalosis? Certainly, the patient's clinical presentation provides a strong clue. If the patient has a history of chronic bronchitis, then the primary problem would be the respiratory acidosis.

Additionally, the blood gas itself provides another clue. One of the fundamental principles in interpreting arterial blood gas results is that the *body never overcompensates*. For example, if the primary problem was a metabolic alkalosis, then the patient would hypoventilate to compensate and his $PaCO_2$ would rise. However, the patient would not hypoventilate to the extent that the pH would have gone to the low (or acidotic) side of the normal range for pH. A pH between 7.40 and 7.45 would be expected, not one between 7.35 and 7.40.

Arterial Blood Gas #2 is a similar arterial blood gas, only partially compensated:

Arterial Blood Gas #2

pH: 7.34
$PaCO_2$: 58 mm Hg
HCO_3: 30 mEq/L

Note that the $PaCO_2$ and HCO_3 are both out of normal range; however, **Arterial Blood Gas #1** has a normal pH while **Arterial Blood Gas #2** has a pH that remains acidotic.

A Word on Oxygenation

An interpretation of an arterial blood gas would not be complete without consideration of the patient's oxygenation status. The patient's oxygenation status is determined by his or her hemoglobin level (Hb) and saturation (SaO_2), the partial pressure of oxygen in his or her arterial blood (PaO_2), the patient's cardiac output, and the fraction of inspired oxygen (FIO_2). Low levels of oxygen in the arterial blood is termed hypoxemia.

Dr. Barry Shapiro, a well-known pulmonologist, has arbitrarily set the following ranges for mild, moderate, and severe hypoxemia:

If the PaO_2 is between 60-79 mm Hg ....the patient has mild hypoxemia.

If the PaO_2 is between 40-59 mm Hg ....the patient has moderate hypoxemia.

If the PaO_2 is less than 40 mm Hg ....the patient has severe hypoxemia.

If the PaO_2 is greater than 79 mm Hg ....the patient has no hypoxemia.

The practitioner must always consider the patient's Hb levels during interpretation. A low or abnormal Hb may result in inadequate amounts of oxygen in the arterial blood (normal Hb level is approximately 15 gram percents (g%)). Similarly, a low cardiac output may cause inadequate delivery of oxygen to the tissues, even though the PaO_2 and Hb values are normal.

Finally, the practitioner must always consider the FIO_2 during his or her interpretation. A PaO_2 of 90 mm Hg is certainly normal; however, if the patient is receiving an FIO_2 of 0.80, then there would be cause for concern. Multiplying the FIO_2 by 500 will provide a rough approximation of the PaO_2 that should result from a given FIO_2 if the patient DOES NOT have an oxygenation problem.

APPENDIX D
EXAMINATION

Arterial Blood Gas Interpretation—Pretest

1. The relationship between $PaCO_2$ and carbon dioxide production is best described as:
   a. directly related
   b. inversely related
   c. exponentially related
   d. curvilinearly related

2. The relationship between $PaCO_2$ and alveolar ventilation is best described as:
   a. directly related
   b. inversely related
   c. exponentially related
   d. curvilinearly related

3. If a patient's carbon dioxide production increases and his $PaCO_2$ has remained constant, what must have happened to his alveolar ventilation?
   a. it must have decreased
   b. it must have increased
   c. it will have remained constant since $PaCO_2$ has remained constant
   d. increases in carbon dioxide production cannot normally occur

4. $PaCO_2$ values will increase if carbon dioxide production remains constant and alveolar ventilation:
   a. increases
   b. decreases
   c. increases at a rate greater than the increase in carbon dioxide production

5. The range for a normal arterial pH is between:
   a. 7.00—7.15
   b. 7.20—7.35
   c. 7.35—7.45
   d. 7.50—7.65

6. The range for a normal $PaCO_2$ value is between:
   a. 25—35 mm Hg
   b. 35—45 mm Hg
   c. 45—55 mm Hg
   d. 55—65 mm Hg

7. The range for normal arterial levels of bicarbonate is between:
   a. 12—18 mEq/L
   b. 18—22 mEq/L
   c. 22—26 mEq/L
   d. 28—32 mEq/L

8. If a patient's carbon dioxide production decreases and his $PaCO_2$ has remained constant, what must have happened to his alveolar ventilation?
   a. it must have increased
   b. it must have decreased
   c. it will have remained constant since $PaCO_2$ has remained constant
   d. decreases in carbon dioxide production cannot normally occur

9. In order to correct an acidotic pH due to high levels of carbon dioxide in the blood, the body will:
   a. excrete bicarbonate through the kidney
   b. decrease carbon dioxide production
   c. retain bicarbonate
   d. decrease minute ventilation

10. A patient on an FIO_2 of 0.40 (40%) has a PaO_2 of 200 mm Hg. This PaO_2 is considered to be:
    a. much lower than predicted
    b. roughly what would be predicted
    c. much higher than predicted
    d. an impossible value

Given the following arterial blood gas results, please interpret them (11-14).

11. pH = 7.46
    $PaCO_2$ = 33 mm Hg
    PaO_2 = 84 mm Hg
    HCO_3 = 23 mEq/L
    FIO_2 = 0.21
    a. fully compensated respiratory acidosis with no hypoxemia
    b. partially compensated metabolic alkalosis without hypoxemia
    c. uncompensated respiratory alkalosis without hypoxemia
    d. normal arterial blood gas

12. pH: 7.33
$PaCO_2$ = 32 mm Hg
PaO_2 = 102 mm Hg
HCO_3 = 19 mEq/L
FIO_2 = 0.5
a. partially compensated metabolic acidosis without hypoxemia but with an oxygenation problem
b. partially compensated respiratory alkalosis without hypoxemia and without an oxygenation problem
c. an impossible blood gas, the pH, $PaCO_2$ and HCO_3 are incompatible
d. fully compensated respiratory alkalosis with mild hypoxemia and an oxygenation problem

13. pH = 7.37
$PaCO_2$ = 64 mm Hg
PaO_2 = 50 mm Hg
HCO_3 = 29 mEq/L
FIO_2 = 0.4
a. fully compensated metabolic alkalosis with severe hypoxemia
b. fully compensated respiratory acidosis with mild hypoxemia
c. partially compensated respiratory acidosis with mild hypoxemia
d. partially compensated metabolic alkalosis with severe hypoxemia

14. pH = 7.44
$PaCO_2$ = 32 mm Hg
PaO_2 = 150 mm Hg
HCO_3 = 30 mEq/L
FIO_2 = 0.21
a. combined respiratory and metabolic alkalosis without hypoxemia
b. fully compensated respiratory alkalosis without hypoxemia
c. fully compensated metabolic alkalosis without hypoxemia
d. an impossible arterial blood gas, the pH, $PaCO_2$ and HCO_3 are incompatible as are the PaO_2 and FIO_2

15. Low levels of oxygen in the blood is termed:
a. hypoxia
b. hyperoxia
c. hypoxemia
d. acidemia

16. ALL of the following determine a patient's oxygenation status EXCEPT for:
    a. hemoglobin levels
    b. saturation of blood with oxygen
    c. PaO2
    d. carbon dioxide production

17. Immediately following vigorous exercise, an athlete has her arterial blood gases analyzed. The results are as follows:

    pH: 7.41
    $PaCO_2$: 38 mm Hg
    PaO_2: 94 mm Hg
    HCO_3: 24 mEq/L
    FIO_2: 0.21

    Based on these results, you could assume that:
    a. the patient had a corresponding increase in her minute ventilation in order to offset increases in her carbon dioxide production
    b. a significant metabolic acidosis has occurred due to poor peripheral perfusion
    c. the athlete has a fully compensated metabolic acidosis due to alveolar hyperventilation
    d. alveolar ventilation has not increased in order to compensate for an increase in carbon dioxide production

18. Which of the following patients would be most likely to have the following arterial blood gas results?

    pH: 7.36
    $PaCO_2$: 64 mm Hg
    PaO_2: 52 mm Hg
    HCO_3: 36 mEq/L
    FIO_2: 0.21

    a. a patient in a great deal of pain and suffering from anxiety attacks
    b. a patient attached to a stomach tube that is suctioning acid from his body
    c. a patient in cardiac arrest who has a severe metabolic acidosis
    d. a patient with chronic obstructive pulmonary disease, such as chronic bronchitis

19. A patient who has been taking too large a dose of diuretics enters the emergency room. Which of the following arterial blood gases would most likely be observed?
    a. a metabolic alkalosis with respiratory compensation
    b. a respiratory acidosis as a method of compensating for her metabolic condition
    c. a metabolic aacidosis without any compensation
    d. a combined respiratory and metabolic acidosis

20. A patient's $PaCO_2$ will decrease if her ____________ increases or her ____________ decreases:
    a. carbon dioxide production . . . alveolar ventilation
    b. alveolar ventilation . . . carbon dioxide production

21. A PaO_2 of 66 mm Hg is considered to be:
    a. normal
    b. mild hypoxemia
    c. moderate hypoxemia
    d. severe hypoxemia

22. A PaO_2 of 76 mm Hg is considered to be:
    a. normal
    b. mild hypoxemia
    c. moderate hypoxemia
    d. severe hypoxemia

23. A PaO_2 of 56 mm Hg is considered to be:
    a. normal
    b. mild hypoxemia
    c. moderate hypoxemia
    d. severe hypoxemia

24. A patient has a pH of 7.42, a $PaCO_2$ of 48 and a HCO_3 of 30 mEq/L. The primary problem is _____________ in nature.
    a. metabolic
    b. respiratory

25. Normal hemoglobin (Hb) level is _____ g%.
    a. 8
    b. 10
    c. 15
    d. 20

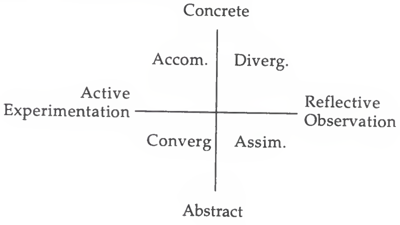
APPENDIX E
INFORMATION SHEET SUPPLIED TO SUBJECTS

The Kolb Learning Style Inventory and How it Relates to You

Background Information on the Kolb LSI:
David Kolb determined that individuals prefer one of four styles or modes for learning new material. These modes are termed active experimentation, concrete experience, abstract conceptualization, and reflective observation. These learning modes have been described as "feeling" (concrete experience), "watching" (reflective observation), "thinking" (abstract conceptualization), and "doing" (active experimentation).

Individuals who utilize concrete learning modes learn best from new experiences, games, role playing; they enjoy peer feedback and discussion; they like personalized counseling and like to view their teachers as coaches and helpers. Individuals who utilize reflective observation modes learn best from lectures; they prefer to take an observational role and to consider different perspectives; they do best on objective tests of knowledge. They view their teachers as guides and taskmasters. Individuals who utilize abstract conceptualization modes learn best from theory readings; they enjoy study time alone; favor clear, well-structured presentations of ideas. They view their instructors as communicators of information. Finally, individuals who utilize active experimentation modes learn best from opportunities to practice and receive feedback; small group discussions; projects and individualized, self-paced learning activities. They view their instructors as role models on how to accomplish tasks.

Combinations of these four modes determine an individual's learning style. The relationships between these four modes are summarized by the following figure:



Characteristics of, strengths of, weaknesses of, careers associated with, and methods of strengthening each of these learning styles are discussed in the following sections.

CONVERGER

Strengths: Problem solving, decision making, deductive reasoning.
Weaknesses: Solving the wrong problem, hasty decision making.
Description: Your dominant learning abilities are Abstract Conceptualization and Active Experimentation. A person with this style seems to do best in situations such as conventional intelligence tests, where there is a single, correct answer or solution to a question or problem. Your knowledge is organized so that through hypothetical-deductive reasoning, you can focus on specific problems. You are relatively unemotional, preferring to deal with things rather than people.

POSSIBLE Careers:

TECHNOLOGICAL		SPECIALIST	
Field	Job	Field	Job
Engineering Medicine	Physician Farming	Mining Forestry	Civil Engineer Production Supervisor
Computer Science	Engineer	Economics	
	Computer Programmer Medical Technician		

The **converger learning style is developed by** experimenting with new ideas, forcing yourself to choose the best solution, setting goals, and making decisions.

DIVERGER

Strengths: Imagination, creativity, understanding people, feeling-oriented.
Weaknesses: Paralyzed by alternatives and indecisiveness.
Description: Your dominant learning abilities are Concrete Experience and Reflective Observation. You are very effective in situations that require "brainstorming" or the generation of ideas. Research indicates that you are interested in people and tend to be imaginative and emotional. You have broad cultural interests and tend to specialize in the arts.

POSSIBLE Careers (Diverger):

ARTS AND ENTERTAINMENT		SERVICE	
Field	Job	Field	Job
Literature Theatre Television Journalism	Actor Athelete Artist Musician	Social Work Psychology Police Nursing	Counselor Therapist Social Worker Personnel Manager Management Consultant

The **diverger learning style is developed by** being sensitive to other people's feelings, being sensitive to values, listening with an open mind, gathering information, and imagining the implications of ambiguous situations.

ASSIMILATOR

Description: Your dominant learning abilities are Abstract Conceptualization and Reflective Observation. You excel in inductive reasoning and assimilating disparate observations into an integrated explanation. You are less interested in people and more interested in abstract concepts for their own sake—application of the ideas are not of paramount importance to you. It is more important that the theory be logically sound and precise. If a theory or plan does not fit the "facts," you are likely to disregard or re-examine the facts.

POSSIBLE Careers:

SCIENCE		INFORMATION	
Field	Job	Field	Job
Mathematics Physical Science Biology	Planner R&D Scientist	Education Clergy	Teacher Writer
	Academic Physician Researcher	Sociology	Librarian
		Law	Minister College Professor

The **assimilator learning style is developed by** organizing information (outlines, organizational charts), building conceptual models, testing theories and ideas, designing experiments, and analyzing quantitative data.

ACCOMMODATOR

Description: Your dominant learning abilities are Active Experimentation and Concrete Experience. Your greatest interest lies in doing things — in carrying out plans and experiments — and involving yourself in new experiences. You are more of a risk-taker than people with other learning styles. The name "Accommodator" was selected because you excel in situations where you must adapt to specific, immediate circumstances. In situations where a theory or plan does not fit the "facts," you will most likely discard the theory or plan. You prefer to solve problems in an intuitive, trail-and-error manner, relying heavily on other people for information rather than on your own analytic ability. You are at ease with people but may occasionally be seen as impatient and "pushy."

POSSIBLE Careers:

BUSINESS AND PROMOTIONAL		ORGANIZATIONAL	
Field	Job	Field	Job
Marketing	Salesperson	Management	Accountant
Government	Politician	Public Administration	Manager
Business	General Manger	Educational Administration	Manager
		Banking	

The **accommodator learning style is developed by** committing yourself to objectives, seeking and exploiting opportunities, influencing and leading others, increasing personal involvement, and dealing with people.

Developing your non-dominant learning style will require you to stretch your comfort zone. However, we must utilize all of the styles in order to maximize our potential.

CONCLUSION

I believe that the method of presenting information may interact with an individual's learning style and, consequently, influence learning and concept attainment. My dissertation will see whether style and presentation mode interact to maximize or diminish learning gains. I could not have done this research without your help. Thank you for your willingness to participate and for the generous donation of your time.

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BIOGRAPHICAL SKETCH

David Nicholas Yonutas was born in Highland Park, Michigan in 1948. He graduated from Lincoln Park High School in 1966 and attended the University of Michigan, graduating in 1970 with a Bachelor of Science degree in biological sciences. He graduated from Michigan State University in 1976 with a Master of Science degree in microbial genetics. In 1977, he earned a certificate of completion in respiratory therapy from the University of Chicago.

Mr. Yonutas has been employed as a respiratory therapist since 1971. He has served as program director of the respiratory care program at Santa Fe Community College since 1985. He has spoken at numerous, local, state, and national conferences on the topic of respiratory care and is a consultant to the Pediatric Pulmonary Center at the University of Florida. Mr. Yonutas has served on state and national professional organizations, including chairing the Florida Society for Respiratory Care's Education Committee and serving as a member of the Education Committee for the American Society for Respiratory Care. He has authored numerous instructional texts, including an instructional manual for the Human Patient Simulator, and a number of self-instructional books on the topics of hemodynamics and mechanical ventilation waveform analysis.

Mr. Yonutas is married to Linda Yonutas and has two children, Nathan and Claire.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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